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(Vol. XIX.—September, 1888.)

SOME FACTS IN RELATION TO FRICTION, WASTE AND LOSS OF WATER IN MAINS.

By CHARLES B. BRUSH, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE 28TH, 1888.

WITH DISCUSSION.

It is well known that many engineers have valuable data which they hesitate to publish because they feel that their experiments are not complete. As a matter of fact, these experiments are seldom completed during one's lifetime, and if the information is not properly tabulated and made known while it is fresh in the mind of the investigator, it is apt to be laid aside and lost. Again, the results obtained are frequently unsatisfactory and do not seem to come up to the standard which is generally expected. An engineer often hesitates about making statements which seem to reflect on the operations of the plant under his control, or upon his own efficiency. In consequence of lack of knowledge as to practical results we have erroneous calculations and false expectations. This paper has been prepared largely with the hope of drawing out the experience of others.

FRICTION, OR HEAD IN FEET NECESSARY TO OBTAIN DIFFERENT VELOCITIES IN PIPES OF GIVEN DIAMETERS.

On November 15th, 1881, the City of Hoboken contracted with the Hackensack Water Company, reorganized, for a new water supply. The plant was ready November 1st, 1882, and since that time it has been in operation. This plant supplied Hoboken, an old unmetered district, for about one year, but after that time it has in addition furnished water to new districts, which never before had a public supply and in which every service pipe is metered. Since 1882 the total of the population supplied in all the districts has been increased from 33 000 to 75 000—the total taps from 2 700 to 5 600—the total meters from 47 to 2 667—the total length of cast-iron main from 16 to 77 miles—while the total amount of water pumped has only increased from 4 000 000 to 4 250 000 United States gallons per day.

For five years the water was pumped to a reservoir through a single line of 20-inch cast-iron pipe, 75 000 feet long, under a static head of 165 feet. The main is laid along railroads and highways with a large number of summits, angles and curves. No special attempt was made to obtain true lines and grades. The exigencies of a public water supply have naturally produced irregularities in our results, but no attempt has been made to harmonize apparent incongruities. The average delivery has been about 4 000 000 gallons per day, but the meter records show that of this amount about 200 000 gallons per day are taken from the main before the balance of the water reaches the reservoir; 100 000 gallons being taken at a point about 13 500 feet from the pumping station and the remaining 100 000 gallons is taken at a point about 70 000 feet from the station. This 200 000 gallons is not leakage; it is water delivered to consumers located at about these points. The main is laid partly in sandy soil, partly through rock cut, and the balance through soft marsh lands. It crosses numerous culverts and small streams, beside passing under two rivers 400 feet wide and from 15 to 25 feet deep. The elevation of the main above mean high tide for the first 34 000 feet is from 2 to 18 feet—at 37 000 feet from the pumping station its elevation is 35 feet—between 36 000 and 48 000 feet from said station the elevation is from 3 to 6 feet, and for the balance of the line the following are the principal elevations:

At 50 000	feet	from the	pumping station	the elevation is 46 feet.
" 52 000	"	"	"	13 "
" 53 000	"	"	"	28 "
" 55 000	"	"	"	20 "
" 60 000	"	"	"	74 "
" 64 500	"	"	"	8 "
" 66 000	"	"	"	29 "
" 69 500	"	"	"	17 "
" 71 000	"	"	"	166 "
" 71 800	"	"	"	157 "
" 73 000	"	"	"	172 "
" 74 000	"	"	"	148 "
" 75 000	"	"	"	180 "

Among the horizontal bends in the pipe there may be mentioned 4 right angles and 10 quadrants of about 30 feet radius.

The friction head on this main has been found to be considerably less than most of the formulas of standard authorities would indicate.

For the purpose of comparison I have tabulated, after allowing 5 per cent. for slip of pumps, the results actually obtained and those obtained from given formulas, using the same data as to head, length and diameter in each case.

This table indicates that the amount of water that can be most economically delivered through a 20-inch main under a static head of 165 feet is about 3 350 000 gallons per day; a delivery which necessitates a velocity 2.36 feet per second and develop a friction head of 1.029 feet per 1 000 feet, or 5.43 feet per mile. Under these conditions the cost of the coal consumed was $8 per million gallons pumped.

With the same pumps (two compound condensing Duplex Low Duty three million gallons Worthington engines) it cost $8.40 and $9 60 per million gallons to pump respectively 2 848 000 and 4 255 200 gallons per day, through the same main.

The increased cost on the lower velocities was probably due to the fact that the plant could not be operated to its greatest efficiency. The increased cost on the higher velocities was probably due to increased friction.

The formulas which agree best with the results we have obtained are those of Lampe and D'Arcy.

RESULTS OBTAINED BY THE HACKENSACK WATER COMPANY, REORGANIZED, FROM 1882–1887 IN PUMPING WATER THROUGH A 20-INCH CAST-IRON MAIN, 75 000 FEET LONG, UNDER CONDITIONS, ABOVE STATED. ALSO RESULTS WITH SAME DATA OBTAINED FROM STANDARD FORMULAS, AS TO FRICTION, VELOCITY AND DISCHARGE.

Table No. 1, *showing actual results obtained by the Hackensack Water Company, Reorganized.*

Pressure in lbs. per sq. in. at Pumping Station	95	100	105	110	115	120	125	130
Total effective head in feet	55	66	77	89	100	112	123	135
Discharge in United States gallons in 24 hours	2 848 000	3 165 200	3 354 250	3 566 800	3 804 400	3 904 200	4 116 750	4 255 200
Actual velocity in main in feet per second	2.00	2.24	2.36	2.52	2.68	2.76	2.92	3.00
Cost of coal consumed in delivering each million United States gallons at given velocities	$8 40	$8 15	$8 00	$8 10	$8 30	$8 60	$9 00	$9 60

Table No. 2, *showing actual and theoretical friction heads per* 1 000 *feet at velocities given in Table No.* 1, *ranging from* 2 *to* 3 *feet per second.*

Hackensack Water Co., Reorganized	0.729	0.876	1.029	1.186	1.337	1.490	1.645	1.797
D'Arcy. $h = .020889 \frac{lv^2}{2\,dg}$	0.779	0.977	1.083	1.236	1.397	1.482	1.659	1.752
Weisbach. $h = \left\{ 0.1439 + \frac{.017155}{v^{\frac{1}{2}}} \right\} \frac{lv^2}{2dg}$	0.998	1.222	1.343	1.505	1.680	1.772	1.963	2.061
Tables published by the Cincinnati and Newport Pipe Co.	0.928	1.146	1.266	1.438	1.615	1.705	1.904	2.008
Prony. $v = 97.05\ (rs)^{\frac{1}{2}}$	1.136	1.371	1.516	1.722	1.940	2.055	2.293	2.417
Kirkwood. $h = \frac{v^2\,l}{1600\,d}$ For tuberculated pipe	1.499	1.880	2.088	2.380	2.692	2.856	3.196	3.374

Table No. 3, showing actual and theoretical velocities in feet per second due to heads given in Table No. 1, ranging from 55 to 135 feet.

Hackensack Water Co., Reorganized	2.00	2.24	2.36	2.52	2.68	2.76	2.92	3.00
Lampe. $v = 203.3\ r^{.694}\ s^{.555}$	2.015	2.231	2.429	2.632	2.809	2.980	3.151	3.318
D'Arcy. $v = 111.00\ (r\,s)^{\frac{1}{2}}$	1.941	2.125	2.295	2.468	2.617	2.770	2.902	3.040
Chezy. $v = 100\ c\ (r\,s)^{\frac{1}{2}}$								
Leslie. $v = 100\ (rs)^{\frac{1}{2}}$	1.747	1.914	2.067	2.201	2.356	2.494	2.648	2.736
Beardmore. $v = 50\left(\frac{hd}{l}\right)^{\frac{1}{2}}$								
Prony. $v = 97.05\ (rs)^{\frac{1}{2}}$	1.695	1.857	2.006	2.146	2.286	2.425	2.569	2.655
Eytelwein. $v = 47.8\left(\frac{hd}{l + 54\ d}\right)^{\frac{1}{2}}$	1.672	1.832	1.978	2.127	2.255	2.386	2.501	2.620
D'Aubuisson. $v = 95.6\,(r\,s)^{\frac{1}{2}}$	1.670	1.839	1.976	2.104	2.252	2.384	2.531	2.616
Blackwell. $v = 95.8\ (r\,s)^{\frac{1}{2}}$. Accounting for curves	1.674	1.834	1.980	2.109	2.257	2.389	2.537	2.621

Table No. 4, showing actual and theoretical discharge, in United States gallons, in 24 hours, due to heads given in Table No. 1, ranging from 55 to 135 feet.

Hackensack Water Co., Reorganized	2 848 000	3 165 200	3 354 250	3 566 800	3 804 400	3 904 200	4 116 750	4 255 200
Lampe	2 848 550	3 153 930	3 433 820	3 720 800	3 971 025	4 212 760	4 454 500	4 690 590
D'Arcy	2 743 950	3 004 060	3 244 390	3 488 960	3 699 600	3 915 900	4 102 490	4 297 580
Chezy								
Leslie	2 469 700	2 705 775	2 922 070	3 111 500	3 330 625	3 525 700	3 743 420	3 867 815
Beardmore								
Prony	2 396 000	2 624 550	2 835 000	3 033 550	3 230 950	3 427 300	3 659 250	3 745 450
Eytelwein	2 363 670	2 589 850	2 796 260	3 006 890	3 187 840	3 373 030	3 535 600	3 703 830
D'Aubuisson	2 360 800	2 599 800	2 793 400	2 974 400	3 183 600	3 370 200	3 578 000	3 698 200
Blackwell	2 366 500	2 592 700	2 799 100	2 981 400	3 190 700	3 377 300	3 586 500	3 705 200

Note. h = head in feet. v = velocity in feet per second. r = hydraulic mean radius = $\frac{1}{4}d$. s = sine of the inclination. l = length in feet. d = diameter in feet. g = 32.2.

D'Arcy's formula, given above, is special for 20-inch pipe. See Paper of Mr. Ellis, read before the American Water Works Association, May 16th, 1883.

Lampe's experiments (Danzig, 1869–71) were made with a 16-inch main on a length of 38 000 feet.

D'Arcy's experiments (Paris, 1849–51) were made with pipes 367 feet long, the largest diameter used being 20 inches.

Nearly all of the other formulas are based on experiments made on pipes of short lengths and comparatively small diameters. The earliest of the formulas given is that of Chezy in 1775. His form, given above, has been followed by most of the later authorities except Weisbach; the principal difference being in their substitution of different constants depending upon the diameter and inclination. Weisbach's constants depend not only upon these, but also upon the velocity. The formulas of Chezy, Leslie and Beardmore are practically the same. The formulas of Prony, Eytelwein, D'Aubuisson and Blackwell agree very closely with each other.

For further particulars see "Hydraulics," by Hamilton Smith, Jr., M. Am. Soc. C. E., 1886.

The mains upon which Lampe and D'Arcy made their experiments were laid with extraordinary care and with a view to these experiments.

Our actual results given in these tables are especially interesting, in view of the fact that only ordinary precautions were taken and no attempt was made to avoid angles, high intermediate summits and numerous sharp curves.

Waste, and Methods of its Prevention, with Special Reference to Metering and Minimum Rates.

On November 1st, 1882, Hoboken had a population of about 33 000 people. About 16 miles of water main had been laid up to that time by the city. For twenty-five years previous Hoboken had been supplied from the Jersey City Water Works, practically under the house-rate system. For the first six months of the first year of the new supply the average daily consumption was nearly four million gallons per day.

I was convinced that one-half of this draft was simply waste, useless and injurious to consumers and disastrous to the Water Company. Prompt action was taken, and the result has been that without inconvenience to the public, without restricting any legitimate use of water, and almost without the knowledge of our consumers, we have reduced this waste to the extent of at least one and-a-half million gallons per day. The waste from the mains and the waste of consumers was about equal, and in each case it has been reduced three-fourths of a million gallons per day.

The following table shows a comparison of the results obtained during the first six months of the first and fifth years of the new supply.

	Six months from November 1st, 1882, to May 1st, 1883.	Six months from November 1st, 1887, to May 1st, 1888.
Population	33 000	41 000
Taps, Unmetered	2 667	2 648
Taps Metered	47	822
Total Taps	2 714	3 470
Daily Draft, United States Gallons:		
Unmetered	3 471 645	2 022 843
Metered	459 099	945 975
Total	3 930 744	2 968 818

It is true that this result is not entirely due to the attachment of meters. Other precautions were also taken. Twice each year house to house inspections were made, as well as night inspections of the mains and service pipes. Nevertheless, the reduction of waste in service pipes was mainly due to metering such consumers as were supposed to be most wasteful. We have found it not only the most effectual method

of restricting waste of consumers, but, as will be hereinafter shown, we have also found that universal metering materially assists in determining leakage from mains.

Since this waste has been checked we have been able to maintain a pressure on the city 25 per cent. higher than was practicable while the waste existed. This has added materially to the efficiency of the fire service, domestic convenience, etc., and thus is of vital interest to the city.

The term "minimum rate," as used in this paper, refers only to metered consumers. It is the least annual amount of money that the Water Company will accept from any consumer. This amount must be paid, even if the quantity of water used during the year does not equal in value this minimum rate. Any quantity of water used in excess of the quantity paid for by the minimum rate, is charged to the consumer at regular schedule prices.

The establishment of a minimum rate is desirable for sanitary reasons, as it prevents a parsimonious use of water. It is usually fixed somewhat below ordinary house rates.

This paper compares the revenue derived from consumers in cases where no minimum rates were in force.

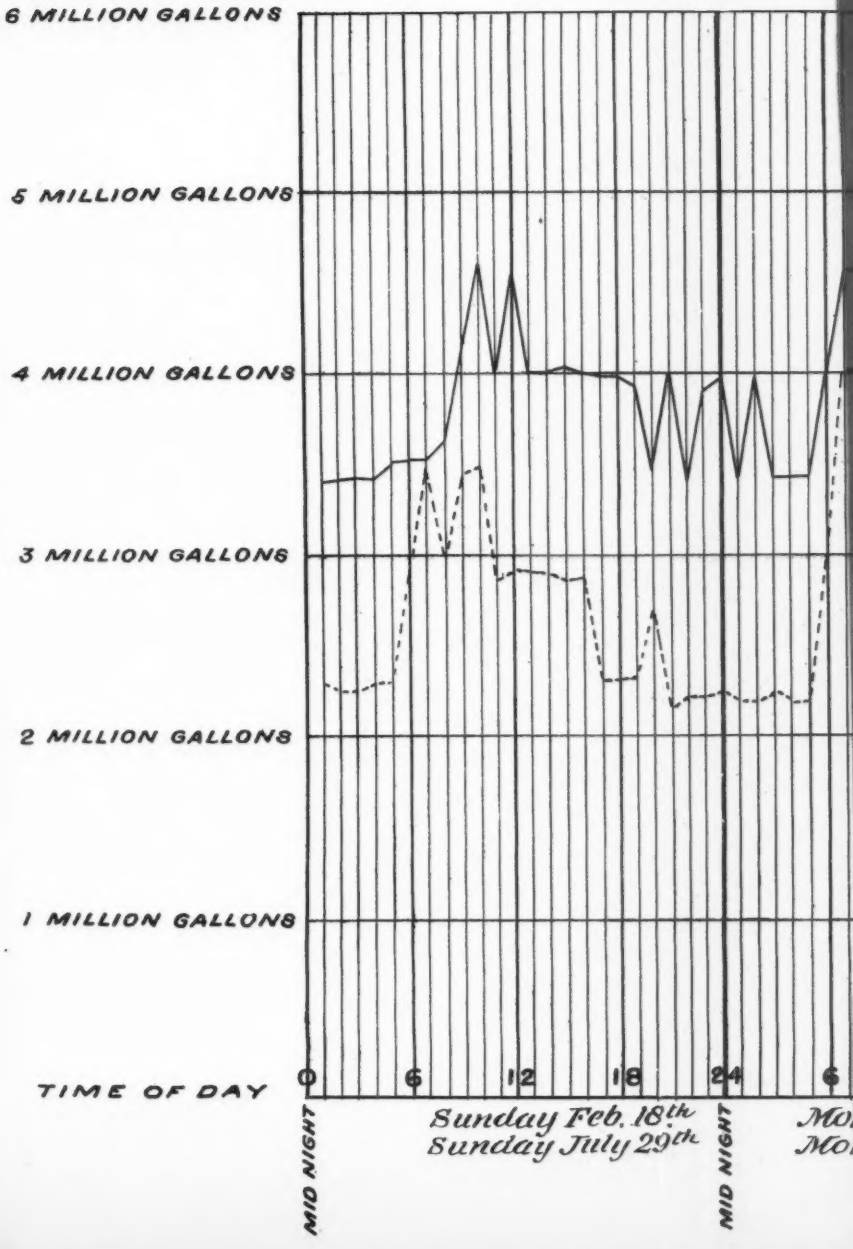
There is no minimum rate in Hoboken, and in a well built-up district, accustomed to a public water supply, the same necessity does not seem to exist for minimum rates as in a locality that has never had such a supply. Even in new localities the amount of water used increases as consumers become better acquainted with the advantages of a public supply, because they find it more economical to obtain water from that source than from existing wells. Nevertheless, in our new districts, after three years' trial without it, we were obliged to establish a low minimum rate.

The diagram, Plate X, annexed to this paper, showing the draft each hour after the waste of Hoboken had been reduced about 32 gallons per head each day, is very suggestive. The draft between 22 and 4 o'clock, even after the reduction, was still at the rate of $2\frac{1}{3}$ millions per day, or 69 gallons per capita.

Where does this water go ?

The legitimate consumption can only be a small percentage of this amount. Since 1883, when this diagram was prepared, the waste of Hoboken has been still further reduced, but the arrangement of our plant is such that it is now impracticable to obtain an accurate record of the hourly draft of this district.

DRAFT IN 24 HOURS



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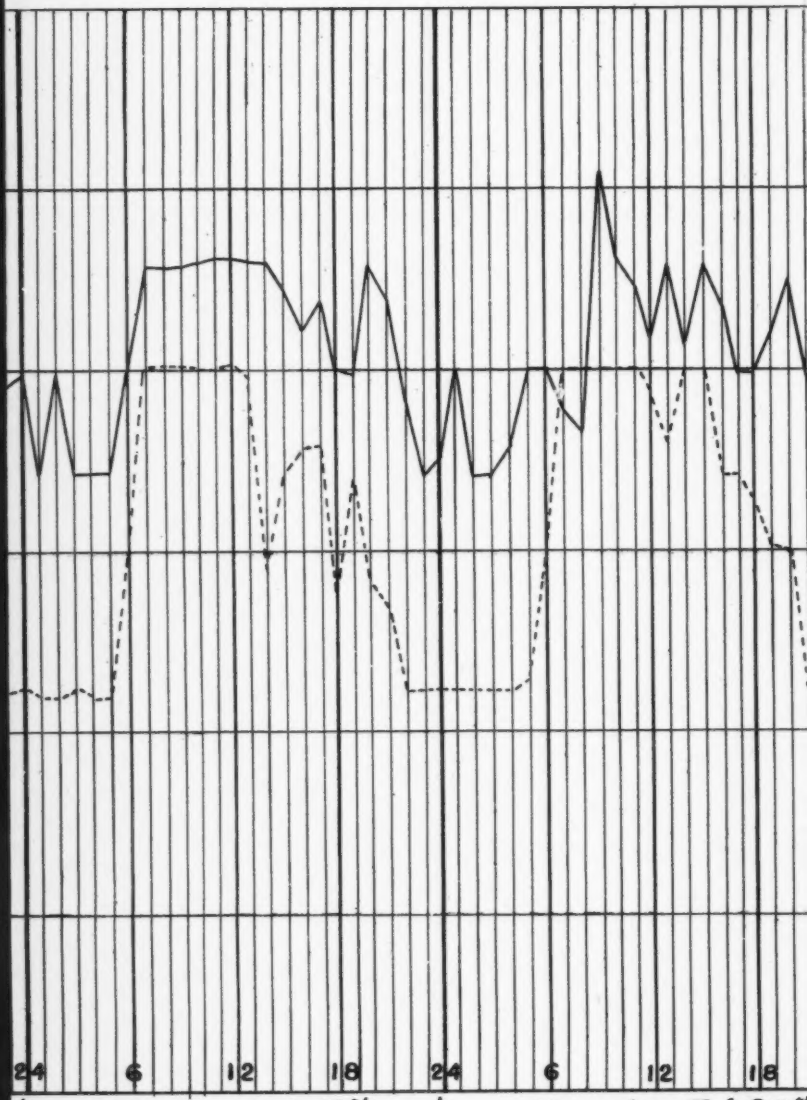
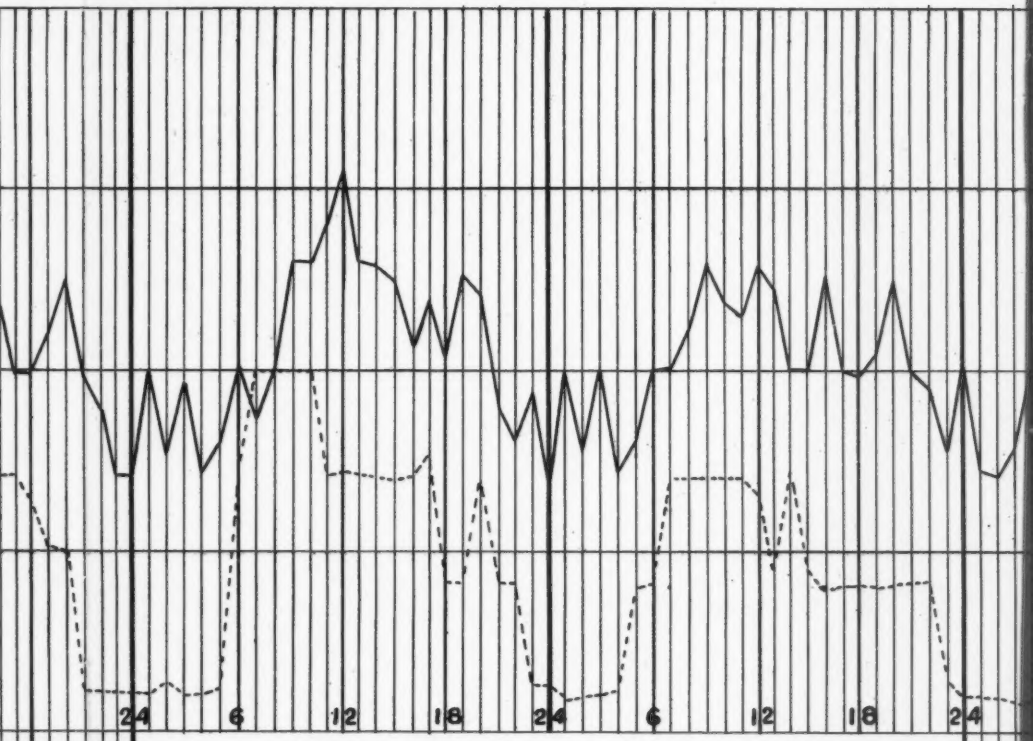


CKENSACK WATER CO., REORGANIZED.

nparison of draft of Hoboken each hour for
Week ending Feb. 24th 1883 shown by full irregular line.
" " Aug. 4th " " " broken " "
Between these dates the waste was largely reduced.



POPULATION OF DISTRICT 34,000

DAILY CONSUMPTION IN GALLONS

Week ending	Average at rate of	Day draft at rate of	Night draft at rate of
Feb. 24th 1883	4,070,000	4,230,000	3,590,000
Aug 4th 1883	2,990,000	3,226,000	2,340,000
Reduction	1,080,000	1,004,000	1,250,000

CONSUMPTION IN GALLONS PER HEAD PER DAY

Week ending	Average	Day Draft	Night Draft
Feb. 24th 1883	120	124	106
Aug. 4th 1883	88	95	69
Reduction	32	29	37

Day draft is taken as between 4 and 22 o'clock.
Night " " " " " 22 " 4 "

18

h 20th
y 31st

MID NIGHT

Wednesday Feb. 21st
Wednesday Aug. 1st

MID NIGHT

Thursday Feb. 22nd
Thursday Aug. 2nd

MID NIGHT

HACKENSACK WATER CO., REORGANIZED.

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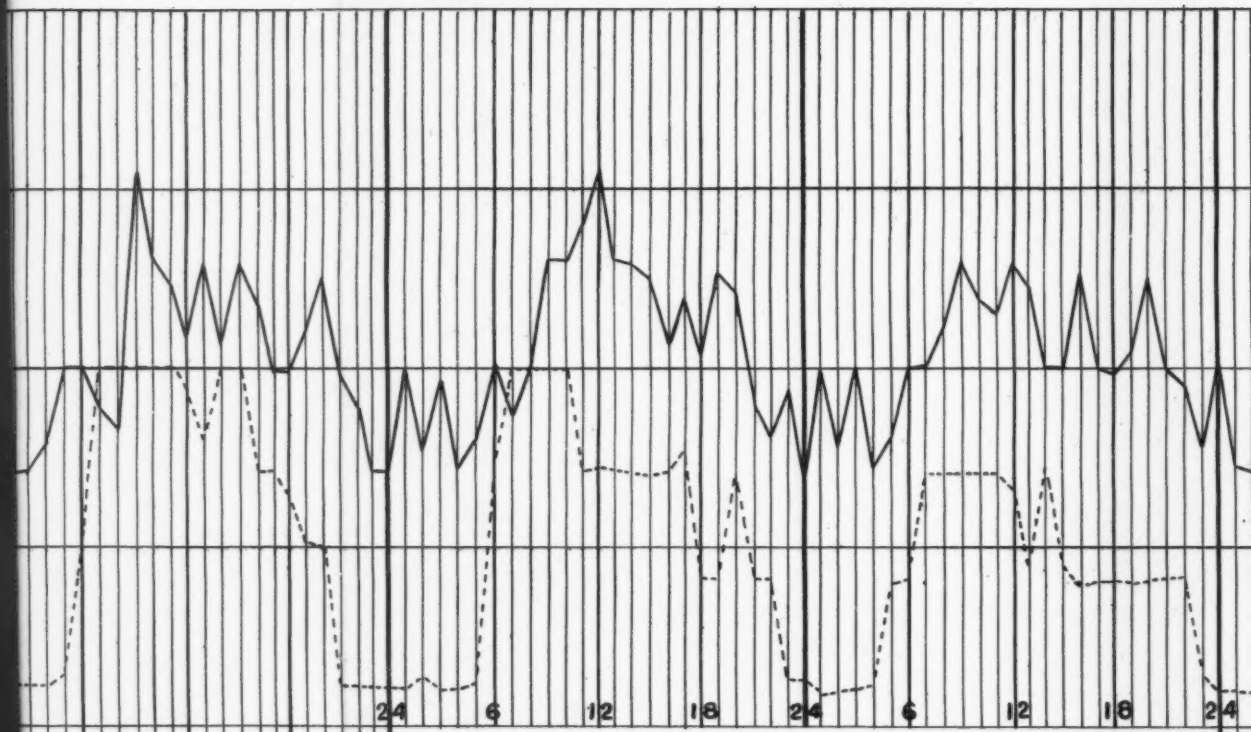

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6 12 18

Tuesday Feb 20th
Tuesday July 31st

MID NIGHT

Wednesday Feb. 21st
Wednesday Aug. 1st

MID NIGHT

Thursday Feb. 22nd
Thursday Aug. 2nd

MID NIGHT

PLATE X
TRANS. AM. SOC. CIV. ENG'NS.
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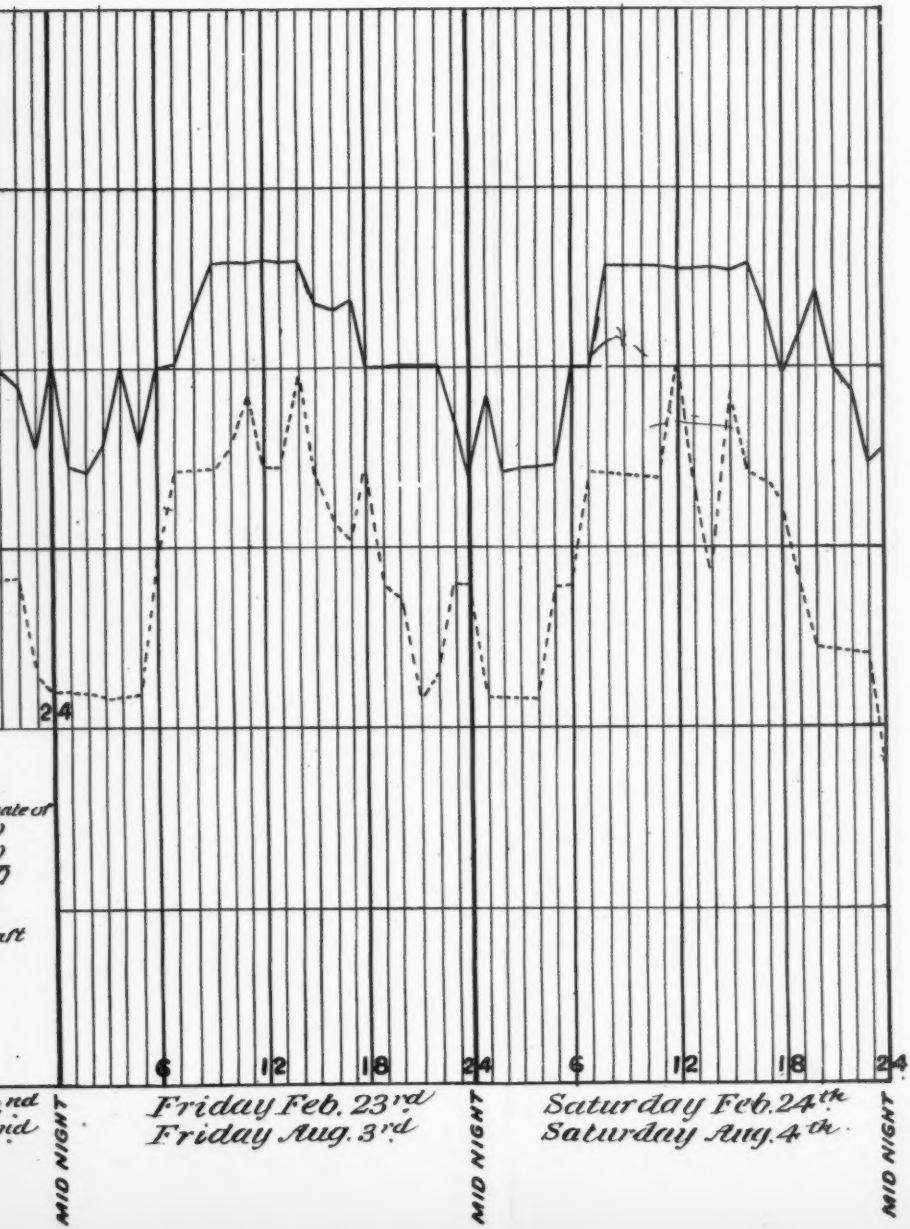
BRUSH ON WATER MAINS



In order to illustrate the ideas I wish to convey, the following tables are submitted.

The actual effect of the attachment of meters during the fall of 1885 on four hundred and thirty-nine houses in Hoboken, previously supplied for many years on the House Rate System, may be ascertained by an examination of the following table:

Consumers.	Amounts Paid by Consumers. Former House Rates.	Present Meter Rates.	Difference.
November 1st, 1885, to February 1st, 1886.			
83 per cent. reduced	$2 978 39	$2 047 92	$930 47
17 " increased	687 41	1 042 73	355 32
	$3 365 80	$3 090 65	Loss, $575 15
February 1st, 1886, to May 1st, 1886.			
63 per cent. reduced	$2 382 13	$1 433 28	$948 85
37 " increased	1 424 87	2 610 50	1 185 53
	$3 807 00	$4 043 78	Gain, $236 68
May 1st, 1886, to August 1st, 1886.			
59 per cent. reduced	$2 254 88	$1 453 26	$801 62
41 " increased	1 566 95	2 775 17	1 208 22
	$3 821 83	$4 228 43	Gain, $406 60
August 1st, 1886, to November 1st, 1886.			
57 per cent. reduced	$2 188 45	$1 447 16	$741 29
43 " increased	1 633 38	2 813 29	1 179 91
	$3 821 83	$4 260 45	Gain, $438 62
November 1st, 1886, to February 1st, 1887.			
72 per cent. reduced	$2 751 72	$1 941 04	$810 68
28 " increased	1 070 11	1 948 81	878 70
	$3 821 83	$3 889 85	Gain, $68 02

Consumers.	Amounts Paid by Consumers. Former House Rates.	Present Meter Rates.	Difference.
February 1st, 1887, to May 1st, 1887.			
75 per cent. reduced	$2 684 71	$1 606 88	$1 077 83
26 " increased	1 025 35	1 661 09	636 74
	$3 710 06	$3 267 97	Loss, $442 09
May 1st, 1887, to August 1st, 1887.			
58 per cent. reduced	$2 216 67	$1 558 00	$658 67
42 " increased	1 605 16	2 737 72	1 132 56
	$3 821 83	$2 895 72	Gain, $473 89
August 1st, 1887, to November 1st, 1887.			
62 per cent. reduced	$2 431 26	$1 580 34	$850 27
38 " increased	1 405 16	2 450 43	1 045 92
	$3 836 42	$4 030 77	Gain, $194 35
November 1st, 1887, to February 1st, 1888.			
67 per cent. reduced	$2 477 78	$1 709 49	$768 29
33 " increased	1 160 37	1 981 67	821 30
	$3 638 15	$3 691 16	Gain, $53 01
February 1st, 1888, to May 1st, 1888.			
70 per cent. reduced	$2 650 14	$1 947 87	$702 27
30 " increased	1 059 92	1 833 83	773 91
	$3 710 00	$3 781 70	Gain, $71 64

In order to ascertain the effect of the meter system in a new district, one hundred and ninety-one average dwellings were selected, connected with our high service plant, which contained about eight occupants to each house. These houses were metered. If house rates in each case had been charged, the daily draft *per capita* would have been about 75 gallons, and the following result would have been obtained:

Houses.	Annual Revenue.	Daily Draft.
191	$2 645 48	115 000 gallons.

The following have been the actual results:

			Annual Revenue.	Daily Draft.
First six months,		winter....	$1 081 32	12 860 gallons.
Second	"	summer...	1 617 26	18 948 "
Third	"	winter....	1 510 44	18 000 "
Fourth	"	summer ..	1 859 94	24 000 "
Fifth	"	winter....	1 385 17	16 550 "
Sixth	"	summer ..	1 959 24	23 000 "
Seventh	"	winter....	1 751 52	21 645 "
Eighth	"	summer ..	2 083 84	25 387 "
Ninth	"	winter....	1 825 92	22 516 "

At house rates each house would have averaged $13 85 per annum.
At meter rates the actual return was $9 56.

At rate of	first six months,	winter.....	$5 66	per annum.
"	second "	summer.....	8 46	"
"	third "	winter.....	7 90	"
"	fourth "	summer.....	9 74	"
"	fifth "	winter.....	7 58	"
"	sixth "	summer.....	10 25	"
"	seventh "	winter.....	9 16	"
"	eighth "	summer.....	10 91	"
"	ninth "	winter.....	9 56	"

Each corresponding period shows a constantly increasing use of water.

It will be noticed that in a metered district the draft in winter is less than that in summer. In unmetered districts the reverse is the case. During the extremes of cold and hot weather the draft *per capita* is about the same in both districts, but after the extreme weather has passed, the waste in the metered district immediately ceases, while in the unmetered district the waste continues for some time.

CLASSIFICATION OF CONSUMERS OF THE HIGH SERVICE DISTRICT OF THE HACKENSACK WATER COMPANY, REORGANIZED, ACCORDING TO AMOUNTS PAID ANNUALLY PREVIOUS TO THE ESTABLISHMENT OF A MINIMUM RATE. ALL THE CONSUMERS WERE METERED.

CLASSIFICATION. Amount of Water consumed per annum.	NO. OF CONSUMERS IN EACH CLASS ON QUARTERS ENDING								
	Feb. 1886.	Nov. 1885.	Aug. 1885.	May 1885.	Feb. 1885.	Nov. 1884.	Aug. 1884.	May 1884.	Feb. 1884.
Between $0 00 and $2 00	164	107	57	128	127	66	37	66	66
2 00 " 4 00	192	165	123	125	107	93	60	46	52
4 00 " 6 00	124	106	67	62	71	67	37	30	25
6 00 " 8 00	55	72	65	38	36	40	32	12	20
8 00 " 10 00	43	45	37	32	30	19	22	16	13
10 00 " 12 00	40	20	39	22	15	16	9	10	8
12 00 " 16 00	49	52	36	21	24	31	24	12	9
16 00 " 20 00	26	27	29	17	14	21	9	5	7
20 00 " 40 00	58	55	69	52	32	37	31	10	7
40 00 " 80 00	12	17	10	10	9	11	7	8	2
80 00 " 200 00	7	5	10	10	4	5	5	4	4
Over $200 00.....	5	5	6	5	5	4	4	3	3
Total.....	775	676	548	522	474	410	277	222	216

It will be seen from this table that during the latest quarter three hundred and fifty-six consumers, out of a total of seven hundred and seventy-five, used less than four dollars worth of water per annum, and practically this proportion of small consumers appears in each of the nine quarters given. In order to check this extreme economical tendency of some of our consumers in a new district, the company was obliged, during the year 1886, to establish a low minimum rate depending upon the size of the meter attached to the consumer's service pipe.

The result of the experience of this water company is that the meter system is mutually advantageous both to the consumer and the company. Each metered consumer pays only for the water he uses, and there are no restrictions either as to quantity used or the time of use. No inquisitorial examination of premises, so unpleasant to consumers, are required. It is the interest of each consumer to have good plumbing. Those who are careless and wasteful, and those who require or desire to use more than an average amount of water, must and should pay for such excess, but the balance, constituting two-thirds of all the

consumers, pay less by meter than by house rates. Meters were attached only after intense and prolonged opposition. Common sense prevailed, however, and now they are quite popular.

Our experience to date indicates that the true policy of a Water Board is to furnish meters and keep them in repair free of expense to the consumer, except in case of misuse or freezing. The meters are then entirely under the control of the Board, who will naturally see that repairs are promptly made. The consumer's interest is rather to see that such repairs are delayed.

The following is an extract from a letter I have received from Wm. G. Richards, Superintendent of the Water Works at Atlanta, Georgia:

"Our works are city property, and are used for almost any and all purposes for which the city can use water, such as puddling ditches after laying sewers or water mains, flushing sewers, and frequently for washing gutters, so that anything like a comparison of the pumping with the meter records would be an impossibility. Then, the public schools are not metered, the city claiming the right to use all the water they want.

"Meters were introduced here as an absolute necessity. The pumpage had become so great, that, with our machinery, it was impossible to maintain a satisfactory pressure, and the city was not in a condition to put in more pumping machinery and a larger pumping main. Meters have now been in general use here about 3 years, and the pumpage does not reach an average of 2 000 000, and before their general introduction it frequently reached 5 000 000 gallons per day. Our number of consumers has regularly increased, but the waste is stopped, and the pressure is satisfactory all over the city."

It is unfortunate that the question of metering is almost synonymous in the public mind with injustice and jobbery. Until a community can be educated so as to grasp the importance of the subject, both from a pecuniary and a sanitary standpoint, and until the moral sense of a community can be sufficiently advanced not to tolerate rascality, such a community will have to suffer and retrograde. The public will learn in time, however, that in most localities the amount of desirable water that can be obtained is limited—that even if it can be obtained in abundance the expense of the supply depends directly upon the quantity—and that the danger to the public health, public safety and the public welfare is directly in proportion to the amount of waste.

Loss of Water from Mains.

In November, 1883, the Hackensack Water Company determined, and has thereafter metered every consumer in each new district it supplied. This is the first instance, I believe, where such radical action has ever been taken. Since that time, Princeton has adopted the same policy, but with this exception I do not know of any other locality where every service is actually metered, though there are many places where a large majority of the taps are metered.

In consequence of universal metering, this company is enabled, in certain districts, to ascertain the difference between the amount of water supposed to be delivered into the mains and the amount drawn through the service pipes of consumers.

The balance may be grouped as follows:

A.—Water drawn through fire hydrants for fire purposes, flushing mains and sewers, settling trenches, street sprinkling, etc.

B.—Slip of pump.

C.—Slip of meters.

D.—Clerical errors.

E.—Leakage from mains.

What becomes of this balance is a question which is receiving earnest consideration. All the meters are tested on large and small streams and found correct before they are attached, and when they are taken off for examination or repairs they are tested and are rarely found inaccurate to a greater extent than three per cent.; usually they come considerably within that limit. We have not as yet sufficient data to determine the proportion of the balance which should be credited under each of the above heads, but the total of the actual balance and such data as we have, I submit in each case, and leave it for you to draw your own conclusions.

High Service District.

The amount of water delivered into these mains is measured by the displacement of the high service pumps. The mains are from 4 inches to 16 inches in diameter, and 22.37 miles long. There are one thousand four hundred and fifty-nine consumers from these mains, and one hundred and ninety-five fire hydrants on this system. The pressure ranges from 25 to 75 pounds per square inch.

Quarter Ending.	No. of Consumers.	Daily Delivered to Mains. U. S. Gals.	Daily measured by separate Meters. U. S. Gals.	Daily Balance. U. S. Gals.	Balance per cent.
November 1st, 1883....	180	45 076	16 213	28 863	64
February 1st, 1884....	227	75 444	33 314	42 130	55
May 1st, 1884....	284	88 785	43 939	44 845	51
August 1st, 1884....	418	137 306	75 886	61 420	45
November 1st, 1884....	487	125 709	77 593	48 116	38
February 1st, 1885....	539	107 508	74 038	33 470	31
May 1st, 1885....	570	138 638	101 503	37 133	27
August 1st, 1885....	702	176 979	130 195	46 784	27
November 1st, 1885....	771	179 385	109 629	69 758	39
February 1st, 1886....	804	166 256	110 537	55 719	33
May 1st, 1886....	830	207 027	126 996	80 031	38
August 1st, 1886....	912	266 281	156 606	109 676	41
November 1st, 1886....	1 035	321 784	186 745	135 038	42
February 1st, 1887....	1 099	311 002	171 051	139 951	45
May 1st, 1887....	1 155	324 473	191 439	133 034	41
August 1st, 1887....	1 271	460 274	276 164	184 130	40
November 1st, 1887....	1 373	452 455	262 424	190 031	42
February 1st, 1888....	1 416	729 640	510 748	218 982	30
May 1st, 1888....	1 459	552 293	270 624	281 569	51

Englewood Distribution Mains.

The amount of water delivered into these mains is measured by a 6-inch meter. The mains are from 4 to 8 inches in diameter and 4.78 miles long. There are eighty-six consumers and forty fire hydrants on this system. The pressure ranges from 25 to 100 pounds per square inch.

Quarter Ending.	No. of Consumers.	Daily Delivered to Mains.	Daily Gallons Measured by Separate Meters.	Daily Balance.	Balance Per Cent.
February 1st, 1888.....	70	9 709	3 883	5 836	60
May 1st, 1888.....	86	17 041	9 543	7 498	44

Ridgefield Pipes.

The amount of water delivered into these mains is measured by a three-quarter inch meter. The pipes are wrought iron, 2 inches in diameter, 0.40 miles long. There are seventeen consumers on this system and no fire hydrants. The pressure ranges from 50 to 100 pounds per square inch.

Quarter Ending.	No. of Consumers.	Daily Delivered to Mains.	Daily Gallons Measured by Separate Meters.	Daily Balance.	Balance Per cent.
November 1st, 1885.....	9	1 487	1 322	165	11
February 1st, 1886.....	11	1 514	1 019	495	32
May 1st, 1886.....	11	2 351	985	1 366	58
August 1st, 1886.....	12	2 917	1 616	1 301	44
November 1st, 1886.....	14	2 325	2 266	59	2
February 1st, 1887.....	17	1 647	1 515	82	4
May 1st, 1887.....	17	1 695	1 534	161	8
August 1st, 1887.....	17	3 672	3 348	324	9
November 1st, 1887.....	17	3 037	2 929	108	4
February 1st, 1888.....	17	3 301	2 968	333	11
May 1st, 1888.....	17	2 858	2 497	361	14

In addition to the above data Prof. Libbey, of the Princeton Water Works, informs me that they have 6 miles of main on which this balance is 20 per cent., or 20 000 gallons per day. He thinks, however, that the loss is principally due to a leak in the main, which he has not yet been able to find, but which he believes he has located within a length of 4 500 feet on a certain main.

Your attention has already been called to the fact that on the 16 miles and more of mains in Hoboken, leakage to the extent of 750 000 gallons per day has actually been checked.

In this connection I also submit an experiment made to determine the leakage on a 24-inch cast-iron force main laid last year by the Hackensack Water Company. The main is 11 miles long, and at the time of the test it was supplied with gates, air-cocks and blow-offs, but no hydrants. The main had been carefully examined under heavy pressure for several weeks after the work was completed, and there was no evidence whatever of leakage. It was connected at both ends with the existing 20-inch main. About midway, the 24-inch main was connected with an iron tank at the summit of the whole system. The test was made by opening the gates at each end of the 24-inch main and filling the tank

under a pressure of 107 pounds per square inch. The gates were then closed and the pressure in the 20-inch main raised to 110 pounds per square inch. The loss on this 24-inch main, 11 miles long, was then found by tank measurement after several trials to be about 70 000 gallons per day. The main was composed of excellent casting, with good lead joints, well caulked and laid by experienced men under careful inspection, by day's work. One thing, at least, is true, viz., that serious leaks may exist in a main under heavy pressure and yet not appear on the surface of the ground.

Perhaps the greatest folly of our time is the almost universal attempt of cities and towns to increase their water supply plant to keep pace with their waste. It is a hopeless task. It amounts to the same thing as attempting to fill a pail which has only a sieve for a bottom. The amount of water that can be used is limited; the amount that can be wasted has no limit. The patience of man has a very positive limit, and therefore I do not consider as waste any amount of water drawn from a self-closing cock held open by hand—drawn for sprinkling gardens, lawns, roads, sidewalks and buildings through a hose held in the hand—drawn for fountains or for use in the various forms of business—but I do insist that water leaking from street mains, service pipes and fixtures out of order, is useful to none, a damage to the individual consumer, and a serious tax on the community. Flushing pipes and drains from time to time is not waste; but allowing small streams of water to run continuously from partially open faucets and cheap water closets is waste of the most serious character, and if not continually watched and checked will soon reach alarming proportions. Where water has to be pumped I do not believe that its use as a motive power is legitimate, except for small eccentric service.

In conclusion, I take pleasure in acknowledging the assistance rendered to me in the preparation of tables given in this paper by L. L. Tribus, Jun. Am. Soc. C. E.

DISCUSSION.

G. H. BENZENBERG, M. Am. Soc. C. E.—I wish to express my personal thanks to Mr. Brush for the presentation of his paper at this time. It refers to a question which has been agitating our citizens here for a year or two past. Our experience with reference to the waste of water has been largely similar to that of Mr. Brush. The consumption per capita here has been from 110 to 115 gallons per day, and rapidly increasing beyond that figure, until last summer it had reached the amount of 128 to 130 gallons per day.

Thereupon, taking advantage of a law which had been passed during the previous winter, meters were largely forced by the department on to the water service pipes, supplying business places and manufactories, and the result was an almost immediate reduction in the demand upon the supply of water, which continued during the entire fall and early winter, until the diminution amounted to almost eight million gallons a day, or a reduction equal to from 38 to 40 per cent. of the present consumption.

During the heaviest consumption last summer the demand had reached to within 5 per cent. of the total pumping capacity and to within 2 per cent. of the capacity of the intake, and the department was without any means or authority to increase either at once, so that the result of placing these meters, materially reducing the waste and increasing the capacity in reserve at the pumping works plant from 2 to 38 per cent., was gratefully appreciated. It was further observed from the record of the consumption taken hourly that the proportionate reduction had been much more during the hours of 11 in the evening to 4 o'clock in the morning, than during any other hours of the day, showing that the reduction had mainly consisted of the former waste. Heretofore the consumption during those hours was at the rate of from 70 to 82 gallons per day to every inhabitant, man, woman and child, in the city, or about 70 per cent. of the average hourly consumption, whereas since last fall the consumption during those same hours is at the rate of about 50 gallons per capita per day, or 60 per cent. of the average hourly consumption, which must, however, still be considered largely as waste.

The number of meters that were connected during the time that this reduction took place was about 1 000, and I mention these facts only as additional proof to what Mr. Brush has stated, that metering is "the most effectual method of restricting waste of consumers."

J. B. FRANCIS, Past President Am. Soc. C. E.—There is one point that I want to ask Mr. Brush about, and that is the condition of the interior of the pipe; the loss due to friction depends very much on the

condition of the interior of the pipe. I have not heard anything about the matter of coating pipes to keep them from oxidation. What means were used, and with what result? If the condition of the interior of the pipe was stated, it would add to the value of the paper.

Mr. BRUSH.—The pipes were new, of cast-iron and coated in the usual way with tar. They have been in use only five years. There was no oxidation on the pipes.

Mr. JOHN W. WESTON.—I would like to ask Mr. Brush if he has experienced any trouble from "wind" in the distribution pipes as we have in Chicago. For several years past the daily papers have had a fund of matter on hand for emergencies, in the way of complaints against the water department on account of insufficient supply and failure in head to reach the upper floors of the ordinary down-town business buildings. An entire change has come about since the advent of the new city administration and the appointment of Mr. F. W. Gerecke, of Newburgh, N. Y., as Chief Engineer.

Immediately on his arrival at the hotel in Chicago, on drawing water Mr. Gerecke noticed the unusual noïse and apparent force of the discharge from the faucet, and raising a glass of water to the light observed a host of air-bubbles rising to the surface. This set him to thinking, which he continued, while making close examinations of the pumping machinery. He found that the valves of certain of the pumps were of faulty construction, so that they would not seat themselves quickly enough to hold all the water. To remedy this, previous officials resorted to the introduction of more air than was allowed in the original construction of the pumps. This was accomplished by regular air-compressors, which were obtained and placed in connection with the pump barrels in the basement of the building. A large amount of air was thus forced into the mains.

Of course the immediate effect was to make the pump valves and pumps work easier, and this would seem to have been the only object considered, as for this purpose air compressors were supplied to both pump houses, and a large amount of air regularly introduced.

Upon taking indicator diagrams from the engines the actual result was somewhat startling; for whereas some 850 horse-power should be required for the work done, the cards only showed 614 as the power actually exerted by that particular engine, demonstrating that nearly a third of the contents of the discharge mains was air.

Since February last, examinations and the necessary overhauling and repairs have been quietly going on, with the results that the pumping machinery has been able to do its work without the air compressor attachments, and that the water supply now reaches the fifth stories of the business buildings of Chicago, whereas for years, practically, it was

impossible to obtain water from the public supply higher than the third.

The discovery of this anomalous condition of a large city's water supply, and the simple changes that effected relief and improved its efficiency, are both curious and interesting.

Mr. BRUSH.—The Hackensack Water Company pumps air into the water for purposes of aeration, but the larger portion of this air in the mains is removed through valves at the summits. The balance of the air, that is not absorbed by the water, passes into our reservoirs. We find this aeration of the water very desirable. We have had no trouble with the air interfering with the flow of water in our mains.

T. J. WHITMAN, M. Am. Soc. C. E.—Has Mr. Brush made any estimates of the loss occasioned by the lead joints of his pipe ?

Mr. BRUSH.—I have not. I do not consider that the serious question as to loss in mains is that of waste at each joint. Many lead joints under heavy pressure show moisture, which indicates small seepage, but this does not amount to much in the aggregate. I refer rather to broken or defective pipes, partially blown out joints, leaky taps, connections and fixtures. When the excavation is partly in earth and partly in rock, in a gravelly or in a moist soil, the water from a leak, instead of coming to the surface often runs along the pipe for a considerable distance, and then disappears without showing at all upon the surface of the ground. We have found several 4-inch connections to fire hydrants broken and the water running off through the soil into the sewers. One of these leaks amounted to 300 000 gallons per day, and it had evidently been running for a long time. These leaks, among others, were discovered during our night inspection of the mains. These examinations are made between midnight and 4 A. M. After a little experience a leak can be quite accurately located by listening to the sound of the water passing through partially closed valves on the mains and service pipes.

The value of the tables on pages 103 and 104 largely consists in the fact that we are forced to admit that leakage and waste exists to a great extent, and are thus driven to the necessity of greater vigilance and more careful examinations. This is our own case at present, and I am confident that we will soon be able to locate this waste and stop it.

Mr. WHITMAN.—From 1871 to 1887, in furnishing water to St. Louis, an hourly statement was kept of the flow of water into the distribution system. We found the same trouble that Mr. Brush has found, viz., a large consumption at night. During the last four years we have taken up about 20 miles of distribution mains located in various parts of the city, and I do not think we found any leaks at the joints. Of course we

have breaks, but the point I want to make is this, that I think the joint we use is the most perfect thing that can be obtained, considering its cost and facility of making, and that leaks of any amount are not due to the joints. If a cap comes off of course there is a large leak, but as I read the paper, it seems to indicate that there were leaks in the mains which would go to show that the plan of the joint was imperfect. I want to make my protest against that view.

Mr. BRUSH.—I agree with Mr. Whitman that a well-made lead joint is excellent and entirely practicable. I refer, however, to special cases of leakage and had no intention of criticising the principle of the lead joint.

J. F. CROWELL, M. Am. Soc. C. E.—I would like to ask if the results through one season show the same equality in the minimum consumption as is here shown for a limited time? Would not these data indicate accidental quantities of the discharge? Suppose at the time of the minimum consumption the pressure is as great as at any other time (the pumping is as great) that would thus indicate a constant leakage.

Mr. BRUSH.—The draft was from a reservoir, not from direct pumping. The pressure therefore increased as the consumption decreased. (Pointing to the (lower) night draft line on the diagram, see Plate X). This straight line indicates that the house waste has been reduced. It is evident that consumers are not allowing water to run at irregular hours in their houses. Any service, running water continually, however, would not have changed the horizontality of this line. We had stopped irregular waste, but the regular waste still continued.

C. F. LOWETH, M. Am. Soc. C. E.—How does Mr. Brush account for the great variations which exist in the last column of the tables on page 13, running from 64 per cent. to 27 per cent.

Mr. BRUSH.—The large variation in the first two quarters of the table to which you refer is due principally to the blowing off of the new main and connections. There is a large amount of water always wasted during the first few quarters of a new supply. You will notice that for the quarter ending May 1st, 1886, the loss was about 80 000 gallons per day, and that this was the greatest loss that had occurred in any quarter during the first three years of the new supply. After this time, an extension was made about five miles in length through a rocky country. This extension is under heavy pressure, and though no leaks appear on the surface I am satisfied that they exist. The value of this table is not

so much in the last column of the percentages as in the preceding column, showing the number of gallons unaccounted for each day. The former is merely relative, depending upon the draft, the latter is positive and is very valuable information.

CHARLES E. GOAD, M. Am. Soc. C. E.—Have you any record of the quantity of water used in fires? Some water works have a method of getting at this. They have a means of knowing when a fire starts and when it has stopped. Then they estimate how much water has been used.

Mr. BRUSH.—The amount of water thus used is comparatively small. It is less than 1 per cent. of our total consumption. We have a large territory to supply, consisting of many municipalities in which small fires frequently occur. Our relations with the fire companies are not as yet well defined, and therefore I am not able at present to control their records. We try to keep the record, but have not been able to do so accurately. I have found, however, that the amount of water used in putting out an ordinary single house fire ranges from 100 000 to 150 000 gallons.

Mr. GOAD.—Have you no record of a large fire?

Mr. BRUSH.—I am very glad to say that I have not.

Mr. BENZENBERG.—If permitted, I might answer that question by giving one experience we had here. The largest fire we have had was the burning of the Newhall House, at which time every fire engine in the city was drawing water for nearly twenty-four hours. The amount of water used was about sixteen per cent. of the general consumption for the day, but there was almost a continuous use for nearly twenty-four hours.

Mr. BRUSH.—About what is the general consumption?

Mr. BENZENBERG.—About 18 500 000 to 19 000 000 gallons.

Mr. GOAD.—How many companies were there?

Mr. BENZENBERG.—There were at that time seven steamers supplying twelve lines of hose.

Mr. GOAD.—The pressure was about 40 pounds?

Mr. BENZENBERG.—About 45; the static pressure is about 50 in that district.

J. T. FANNING, M. Am. Soc. C. E.—Mr. Brush's paper has suggested interesting lines of thought. I will add a word respecting the valuable Table of Experimental and Theoretical Data relating to the flow of water in his 20-inch diameter main. I am glad that we have the results of his investigations of formulas in this compact form, and especially that he has thus given the results of careful experiments.

Our members ought to be stimulated by this paper to give to the Society the results of their accurate experiments, even though they cover but limited range, so that they may be used in comparison with other similar data and in scientific deductions.

Often, in our practice, we are confronted with new problems, which we can not solve with certainty without the aid of some experimental data.

I recall perplexities in my own early work connected with the use of formulas for flow of water in pipes, as then given in the hand books of the day.

In planning, twenty-five years ago, the water supply for a small city, I was much puzzled in attempting to determine the quantity of water that would be delivered by gravity, through a supply main, to the city, from a gathering reservoir seven miles distant.

Whether the pipe might be 12 inches diameter or must be 16 inches diameter, was so important, that it would decide the question in favor or against the construction of the works, for the largest main would cost 50 per cent. more than the smaller, and the total cost of the works would be increased thereby to an amount that would be considered financially prohibitive.

I compared the results given by the various formulas for total volume of flow under the given total head, and for the amount of head consumed by given lesser volumes of flow, and found extreme discrepancies for like data, which lead to an exasperating uncertainty.

The formulas of Chezy, Leslie, Beardmore, Prony, D'Aubuisson and Blackwell, which are given by Mr. Brush, were then accessible, and gave tolerably agreeing results for the given case, but they gave results differing from the formulas of Du Buat and Weisbach, and on testing with varied diameters and velocities of flow were so discordant as to leave much doubt about which was most trustworthy, or in fact if either might be relied upon in a case of so much importance. I had not at that early date the advantage of Kutter's investigations, and was forced to gather for the purpose of testing these formulas all the experimental results of velocities and volumes of flow in pipes that I could obtain and to compute their co-efficients.*

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* This necessitated the tracing of the origin of the co-efficient as it appears in the formula $v = 100\ (ri)^{\frac{1}{2}}$. The 100 includes the constant factor $\sqrt{2g}$ and the reciprocal of an experimental or variable co-efficient whose symbol is m, whence the co-efficient $100 = \sqrt{\frac{2g}{m}}$. Using these terms, it is evident that the formula for v, in long pipes, may be written in the following equivalent forms, $v = c\ (r\ i)\ \frac{1}{2} = 100\ (r\ i)\ \frac{1}{2} = \sqrt{\frac{2\,g\,ri}{m}} = \sqrt{\frac{2\,gd\,n}{4\,ml}}$ from which we have $m = \frac{2\,g\,ri}{v^2} = \frac{2\,g\,d\,h}{4\,7\,v^2}$

As the reduction of experimental co-efficients proceeded, it became evident that the prefixed co-efficient of the formula was not even approximately a constant, but that it varied with diameter of pipe and with velocity of flow.

Plotting the experimental co-efficients of one size of pipe for different rates of flow, using velocities for ordinates and co-efficients for abscisses, and then similarly plotting for other sizes of pipes, I found the plotted points of co-efficients for each size of pipe to lie very nearly in lines of parabolic curvature, and for the different sizes of pipes nearly concentric, but curving more rapidly and tending toward a common point as velocity became small, and tending to parallelism as velocity became excessive.

On readjusting the curves in accordance with the apparent law of increase and decrease of co-efficients, I was then able to fill in curves for the intermediate sizes of pipes not covered by experiments, and to continue the curves slightly beyond the range of experiment, so as to cover the range of ordinary uses of pipes under pressure in water supply systems.*

The diagram indicates that the value of c, which Mr. Brush gives here in Table No. 3 in the Chezy and Leslie formulas, had a range in ordinary city pipe systems and with medium velocities of flow, from about 90 to 135, and that the experience co-efficient embodied in this c had a range from about .0034 to .0074, while c, when of precisely the value 100, corresponds to the experimental co-efficient .00644; also that in clean service pipes the c might have a value as low as 70.

With the aid of the diagram I saw that the first difficulty with the use of the formulas was that I had previously lacked properly classified knowledge of the conditions of flow in pipes to adapt the variables of the formulas, which were given as constants, to the particular case in hand.

With the separation of the formulas into their several factors, and tracing the ranges of the variables in the diagram, there came a revelation of wide significance as to the flow of water under pressure. It appeared that all those formulas, similar to the last seven of the nine formulas given here in Mr. Brush's Table No. 3, are practically identical, and that so long as their co-efficient c, or 100, is treated as constant, the formula applies to only one condition of rate of flow in a given pipe, and to one other rate of flow only in any other size of pipe, and thus if I applied them to my 12-inch pipe they were adapted to a velocity of about $\frac{6}{10}$ths-foot per second, and if to the 16-inch pipe, to a velocity of about $\frac{1}{10}$th-foot per second. These velocities were far below those that must necessarily be used in the case then being considered.

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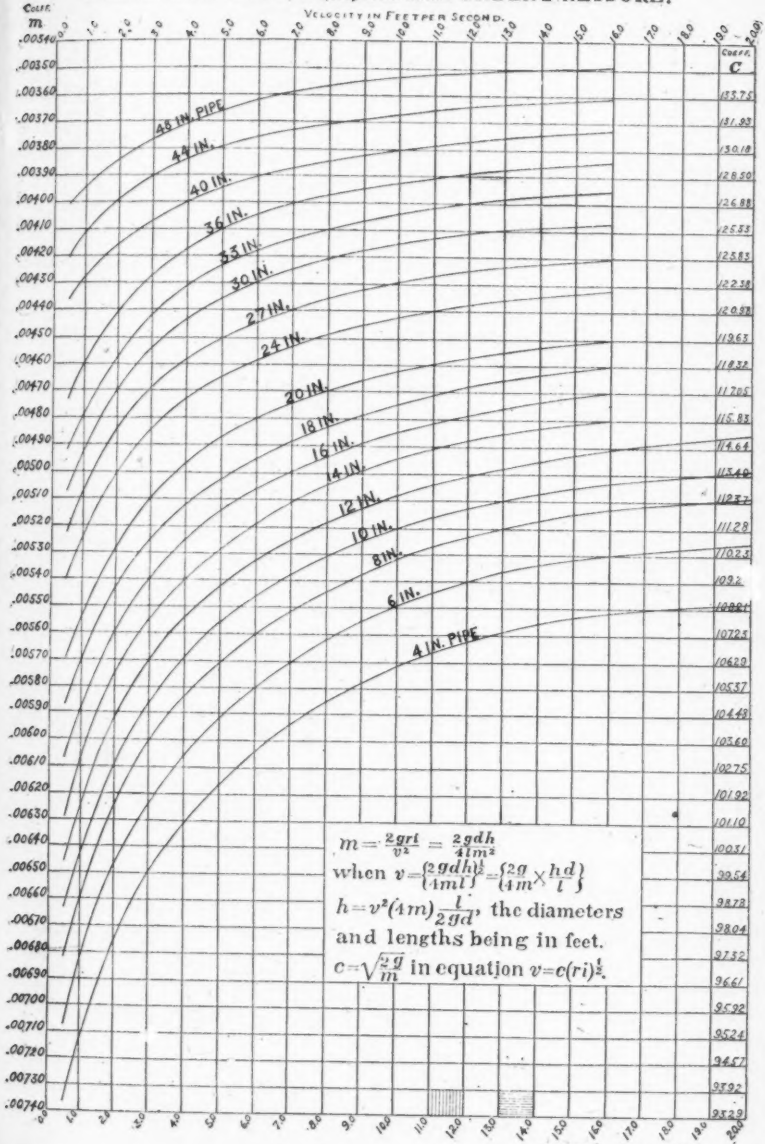
* A reduced copy of the diagram alluded to is presented herewith, Plate XI.

DIAGRAM OF
COEFFICIENTS OF FLOW (m) IN PIPES UNDER PRESSURE.



J. T. FANNING, C.E.

Vol. XIX, p. 112. PLATE XI—FANNING ON FLOW IN PIPES.

In computing for loss of head, or "friction-head," as it is termed, we have frequently to use the formulas when velocities are from 10 to 12 feet per second, and when computing for total capacities of pipes, the velocities are very great, and formulas with constant co-efficients give misleading results.

Mr. Brush has applied these formulas of Table No. 3 to a 20 inch pipe within the very limited experimental range of velocity from 2-feet to 3 feet per second, and yet it appears, as we scan over the table, that none of them were sufficiently well adapted to his case. He finds D'Arcy's formula, which his foot note says is made special for a 20-inch pipe, to best fit his experimental velocities and volumes. He has used it with the co-efficient a constant, and we see the results for volumes in Table No. 4, where, when velocity was 2 feet and measured volume at rate of 2 848 000 gallons per day, the formula gave 2 743 050 gallons, about 100 000 gallons short. When velocity was three feet and measured volume at rate of 4 255 200 gallons per day, the formula gave 4 297 580 gallons, about 42 000 gallons in excess.

If we plot the experimental and theoretical curves for this one limited series, we will find their lines to cross, and at the same time it appears the D'Arcy co-efficient is 11 per cent in excess of the co-efficients of the following formulas, and consequently gives, in this case, volumes about 11 per cent. nearer the true volumes than the others. If the co-efficient had been varied with variation of velocity as experience indicates proper, then the experimental and theoretical curves of velocities and volumes would have been respectively identical.

My diagram and the table of co-efficients taken therefrom has been very suggestive in a long practice, and has simplified many problems, not only relating to smooth pipes, but to conduits and sewers, that without its teachings would have proved very intricate. By similarly plotting for rough pipes and open channels, the new positions for their co-efficient curves are readily suggested.

A table of co-efficients for smooth pipes need not be very extensive for ordinary practice, and one page of the note book will give ample place for a series covering the range of pipes from 4 to 48 inches diameter.

The c of the Chezy formula is the symbol of a compound factor, but is readily deduced from the co-efficients of variables as diagramed. If we take $\frac{1}{m}$ as the symbol of the variables, such as are determined by experiment, then we find c to equal $\sqrt{\frac{2g}{m}}$.

If $c = 100 = \sqrt{\frac{2g}{m}}$ then $m = \frac{64.4}{100^2} = .00644$, and for other values of c we have $\frac{64.4}{m} = c^2$.

Thus the series of c may be diagramed or tabled as fully as the series of m for either pipes, sewers or open channels.

Toward the close of our morning session the discussion had turned to

The Use of Water Mains for Fire Purposes.

A matter of general interest in that line happened in one of the large cities in the Northwest during the last winter.

There were two large fires within one week in the wholesale district in St. Paul, at each of which an extensive warehouse with contents was destroyed. The division of the water mains controlling the fire service of this district extends northerly back from the river five blocks, and from east to west, parallel with the river, seven blocks.

The water is supplied by gravity, a 20-inch pipe coming to the northeast corner, and a 12-inch pipe to the northwest corner of the district. There is a 16-inch main along the east side, a 12-inch main along the north side, and a 12-inch main along the west side of the district, and this district is gridironed across in all its streets with 6 and 4-inch pipes, and has fire hydrants at each street corner.

At each of the fires nine steam fire engines were in use, and it was claimed that a number of the engines were occasionally unable to get a sufficient supply of water, and that by their suctions they were occasionally causing vacuums in the hydrants, and that the force and volume of the fire streams were thus diminished and ineffectual at times.

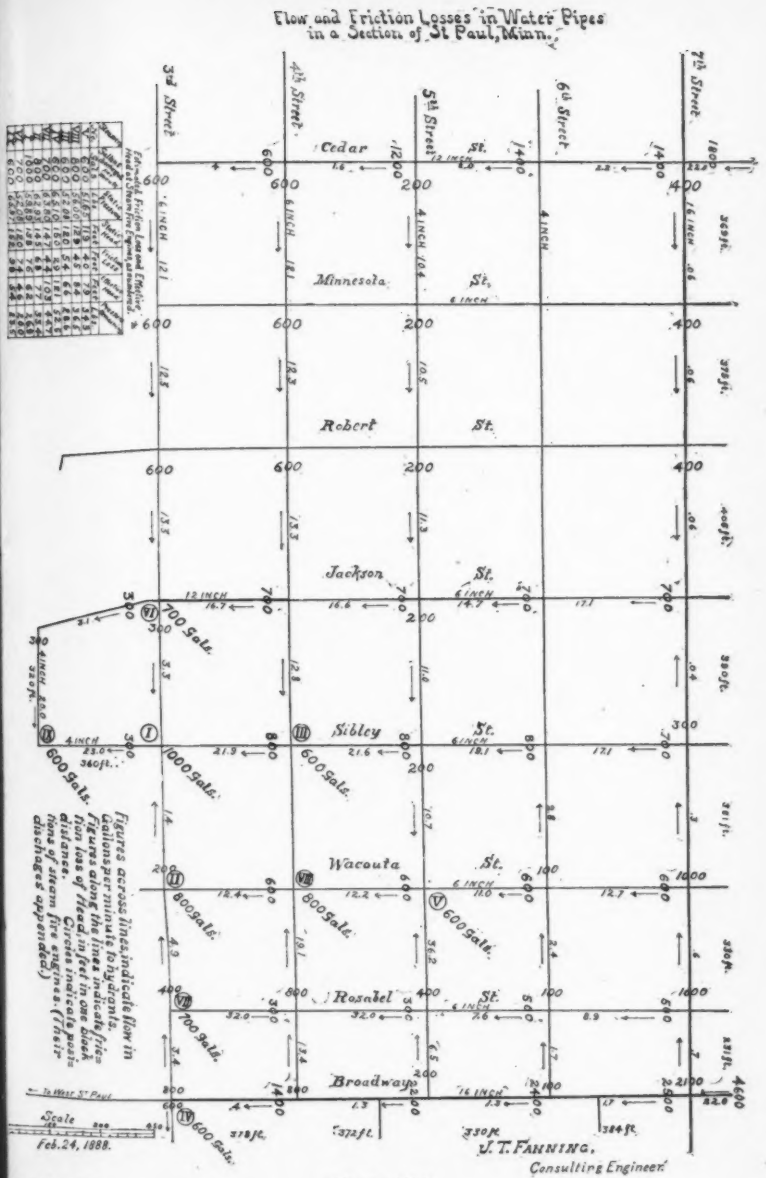
This claim led to the impression that the water mains in the district had not capacity to supply the fire steamers in use, and to severe criticisms of the Water Commissioners, and also to an immediate raising of fire insurance rates in the wholesale district.

The Water Commissioners believed they were unjustly blamed, and asked the speaker to investigate and report to them the capacity of the mains in the district.

Considering the climatic conditions of St. Paul's February, the immediate investigation could not readily be other than a theoretical examination of the conditions of flow in the mains, and there became involved here some of the interesting questions which Mr. Brush has suggested in his tables of experiments and theoretical flow in mains.

The static head of water under the condition of domestic consumption at that time was determined in the wholesale district by gauges, and found to be at the location of the lowest hydrant 152 feet head, and at the highest hydrant 119 feet head, with a mean head in the immediate vicinity of the ruins of the two burned warehouses of 135.5 feet, or 58.8 pounds pressure.

The capacities of the steam fire engines were claimed by those in charge of them to be as follows: four steamers, 600 gallons; two steam-



Vol. XIX, p. 114.

PLATE XII.

ers, 700 gallons; two steamers, 800 gallons; and one steamer, 1 000 gallons; making a total for the nine steamers of 6 400 gallons per minute. As there were at the fires thirteen streams in play the greater part of the time, this would give to each stream an average of 492 gallons per minute. As I had found in tests of hydrant streams under high gravity pressure that 30 cubic feet, or 225 gallons per minute from a 1¼-inch nozzle made an excellent fire stream, I believed the capacities of the steamers to be stated much higher than their regular working capacities, but decided to base the computation on the claimed discharge of water as a possible excessive condition.

On a skeleton map of the pipes of this district was figured the estimated volumes of flow from the three large surrounding mains into and through the cross-distribution mains toward the hydrants in use, displaying at a glance the assumed volume of flow along each block and in each pipe. (See Plate XII).

The loss of pressure along each block in the direction of the hydrants was then computed and summed to obtain the total loss at each hydrant in use by a steamer, the estimated volumes of domestic use being included in computing frictional losses.

The computation indicated that even though the steamers reached the improbable discharge of 6 400 gallons per minute, there remained throughout the district a mean pressure of at least 34 pounds per square inch at the hydrant nozzles, and therefore, if not impossible, it was certainly improbable that there was any approach to a vacuum in any hydrant in use, if its valve was fully open. The claims of the Water Commissioners that the failure of the fire streams was not chargeable to any defect in the water mains being still opposed, the Commissioners asked that a thorough test be made of the mains with the fire steamers again in position as at the time of the last large fire, and that gauges be applied on the mains and hydrants, and their pressures be observed.

After much public discussion of the question, such a test was decided upon, and Mr. J. W. Hill, M. Am. Soc. C. E., was selected to direct the same.

Such a thorough test was made a few weeks since with nine steam fire engines and fifteen streams in use, and we are now waiting for the report, which we are confident will give voluminous experimental data that will be valuable to members of this society and to the profession.

The active test was continued during a period of four hours, which gave ample opportunity to observe the readings of the gauges and the actions of the steamers and their streams. The engines were worked so vigorously during the first hour that the highest readings of their respective water gauges were noted to range from 200 to 275 pounds, and yet it was evident by the readings of the pressure gauges on the hydrants that the combined discharges of all the engines was not so great as their claimed rating, which I have previously stated.

Occasionally, with 40 to 45 pounds pressure on the hydrant gauge, as a steamer was speeded up, it would apparently be short of water, and its stream would diminish.

Observing on such occasions that the pressure rose in the hydrant gauge and diminished in the steamer's water gauge proportionally as the hose stream diminished, it was evident that the supposed vacuum, that had caused so much discussion, was not in the hydrant, but was probably between the suction valves and the pump piston, and hence a conclusion that the piston speed at its maximum was greater than water could follow through the grid of the valve seat, and that the pump chamber was but partially filled with water at each stroke of the piston.

To further test whether the hydrant gauges were deceptive as to pressure, I directed that a hose be attached to the spare nozzle of a hydrant while the steamers were in full work.

A direct pressure stream was thus obtained, which accounted for the pressure indicated by the gauge, and this direct pressure stream through a short hose was about equal in force to the stream from the adjoining steamer delivered through a longer hose.

I will not attempt to offer general deductions from memory of my notes or observations. Mr. Hill has the complete records of observations of the forty-eight gauges for the preparation of his report, and I anticipate that the report will be so full and able that it will put us in possession of many new and valuable facts relating to the frictions of flow of water through pipes in fire service.

A. Fteley, M. Am. Soc. C. E.—After hearing the paper just read, it occurs to me that aside from its merit in presenting numerous data collected from a long series of observations, it has the additional advantage of giving us all the results obtained, as they are collected, regardless of the fact that they may not have been, at times, as satisfactory as might have been expected.

This course is very commendable, and in the present case, the usefulness of the results furnished is enhanced by the well-known care and ability displayed by the author in the conduct of his work.

Not having been connected lately with the management of any water distribution, I regret not to be able, at present, to give any new fact of interest in connection with this question, but I will ask Mr. Brush to give us, if possible, some additional figures in regard to his observations of the flow of water through a 20-inch pipe.

The results furnished by him give the average of a great many observations. Some of the individual results may vary considerably from the average, either one way or the other, and the knowledge of the range and distribution of these variations would be interesting.

A short description of the particular conditions obtaining at the time that such variations were observed, would also be of great interest.

In the conduct of experiments of this character, the more accurately the conditions prevailing at the time of the observations are described, the more convincing are the deductions made and the more confidently they can be received and applied.

The remarks just made by Mr. Fanning in regard to the difficulty of harmonizing the results furnished by various experimenters for the flow through pipes of the same diameter, illustrate well the probable fact that the difference of the results obtained in apparently identical circumstances, is due to the existence of individual conditions, which have been ignored or incompletely described by the experimenters.

I consequently believe that the author of the paper would add to its interest by giving a tabulated list of his results, with such remarks as might be of interest in connection with them. The reader would then be able, by a study of individual observations, to select those which are more applicable to his case, and to draw his own conclusions.

Before closing these remarks, I may be permitted to recall here and to deplore the death of the modest and able engineer, to whom our profession is indebted for the formulation of his admirable research on the flow of water, W. R. Kutter, of Switzerland.

Mr. BRUSH.—The information requested by Mr. Fteley I will be very glad to furnish. Our system is to take the record every hour during the twenty-four hours of the day. Therefore we know the velocities at which we were pumping at different times during different days. From the experience of five years and taking the average of the results obtained when running at given velocities during this whole period, I have obtained the data presented in my paper. I will present hereafter, as requested, a more definite statement of the number of these experiments.

MANSFIELD MERRIMAN, M. Am. Soc. C. E.—Were the velocities which are given in the first table of the paper determined by displacement of the pump?

Mr. BRUSH.—By the displacement of the pump. This was compared during the first two months of our supply with the amount of water delivered into the reservoir. We knew exactly the size of the reservoir and its capacity for every inch of height. We found that the difference was not more than 3 per cent. I have allowed 5 per cent., extending over the whole period of five years, as loss by pump displacement, *et als.*

OBERLIN SMITH, M. Am. Soc. C. E.—I would like to ask Mr. Brush a question or two.

First.—Whether he has made experiments with the ordinary cast-iron main joints, following out the average loss? It seems to me that the

figures in the last column of the first table on page 103 are remarkable. What I want to know is, about what proportion of this 64 per cent. is due to the leakage of the cast-iron main; whether he has an idea of the average loss due to the leakage of the cast-iron main, which of course is a certain part of this 64 per cent.?

The other question is whether he has experimented with large wrought-iron pipes in place of cast-iron, and, if so, if he finds much difference?

Mr. BRUSH.—The 64 per cent., as I explained this morning, was the loss during the first quarter, and that was due to the amount of water that was blown off to clean the main. As I said, these percentages are only relative. There is a constant amount of water which has to be wasted from every distribution system in order to keep the pipes clean for fire purposes, for sprinkling streets, etc. Therefore, the earlier percentages in the table are of little value. As a matter of fact, the preceding column in the table gives you a better guide as to the actual amount of loss than the percentages in the last column.

I have had considerable experience with small wrought-iron pipe buried in the ground, and it has been unsatisfactory. There is great lack of uniformity in its durability. On the same line of pipe one portion will last a long time, while another portion will soon wear out. The difference seems to depend on the soil in which the pipe is laid. Ashes especially will soon destroy wrought-iron pipe, often during the first year. My observation on large wrought-iron pipe, underground, leads me to distrust it for water mains in this section of our country. There is a marked difference in the climatic conditions of the Pacific Coast, where this pipe has been successfully used, and our Atlantic Coast.

G. W. PEARSONS, M. Am. Soc. C. E.—I would say that my experience in the use of perhaps 200 miles of cast-iron mains leads me to think that no important leaks can exist without showing at the surface, unless some access is made by the leak to subterranean drains, either natural or artificial.

In one case I dug up a place where, in dry loamy ground, the water had come to the surface and formed quite a pool; the leak, when found, proved to be a single stream about as large as a fine cambric needle, certainly less than one-fortieth of an inch in diameter.

In another case a line of 20-inch pipe, with Robbins' patent joints, showed for over a mile by the settlement of the newly-filled trench the location of almost every joint; these soon closed, and the pipe became so tight as to allow the ground to dry with the rest, and in subsequent digging for connections no leaks or wet places were discovered. This was in dense clay soil, where a very slight leak would have the effect of keeping the ground saturated.

In another case a 9-inch pipe carrying water from a mountain lake, so clear that the proprietors of the works scouted the idea of any sediment having ever entered the pipe, became entirely closed by the accumulation of soft silt in the pipe.

I think that it is safe to estimate that not the hundredth part of one per cent. of discovered loss is due to actual leakage through the pipe or its joints; but a reverse action taking place in all valves and connections, these almost certainly become leaky by use. I have seen thirteen valves of from 4 to 6 inches closed for repair, and a steam fire engine have all it could do to keep the trench clear, and this is not an isolated or exceptional case. Service pipes have access to drainage, and their leakage is only reported where it is annoying; the still joints of the main lines, if leaky at first, soon close by silt.

Mr. BENZENBERG.—I suppose I could add a word as to what we found here in seeking for the causes of the enormous wasteage of water in Milwaukee. The regulations here require that wherever a street is to be paved the water service pipes and house drains must be laid to each lot.

In looking for leaks and waste of water with the aid of the Bell waterphone, it was discovered that in one square or block, out of four service pipes which had with the drain pipe been laid to the curb line, and which had never been extended, there being no improvements of any kind on said lots, three were discharging water without any indication on the surface.

On digging down it was found that the stop-cocks at the curb had been left wide open, and the water was discharging direct into the drains, which had been laid at the same time, evidently from the very first minute that the pipe had been laid, the plumber having left the stop cock open when he had finished the work.

As I said, there were three such cases in one block. This of course led us to look for wastes in a direction new to us.

SUMMARY BY MR. BRUSH, SEPTEMBER 13TH, 1888.

Since this paper was read and discussed at our Annual Convention last June, I have obtained from Warren E. Hill, M. Am. Soc. C. E., the following valuable data:

EXPERIMENTS ON THE DELIVERY OF WATER FROM PIPES, MADE BY THOMAS F. ROWLAND, CONTINENTAL WORKS, GREENPOINT, BROOKLYN, N. Y., JULY 19TH, 1883.

These experiments were made at the works of the New York Gaslight Company, Twenty-first street and Avenue A, on ¾-inch, ½-inch and 1-inch wrought-iron steam-pipes of varying lengths, and under varying pressures. The object was to ascertain whether Eytelwein's formula for the flow of water in pipes, is applicable to pipes of small diameter, and if it is not, to make the proper correction in the constant.

Eytelwein's formula is as follows: $Q=4.72\sqrt{\frac{D^5 H}{L}}$ in which Q is the quantity of water delivered per minute in cubic feet; D, the diameter of the pipe in inches; H, the head of water in feet, and L, the length of pipe in feet.

The water was delivered from an accumulator by a 2½-inch pipe, and the pressure was taken from an Ashcroft gauge placed near the junction of this pipe, and the pipes to be experimented upon. A 2½-inch globe valve, placed between the gauge and the accumulator, served to regulate the pressure to a nicety. The water was delivered into a barrel under full head, promptly and without any loss. It was weighed on a Fairbank's scale; the time was taken with a "stop watch."

These experiments show that the constant (4.72) in Eytelwein's formula should be as follows:

For	¾-inch pipe, 30— 60 feet long	6.90
	½-inch pipe, 30— 60 "	6.98
	1-inch pipe, 30—100 "	4.85

This is for straight pipe. It was found that two elbows or a return bend would reduce the delivery 2 or 4 per cent.

TABLE.

Experiments.	Size of Pipe in inches.	Length of Pipe in feet.	Pressure in pounds per square inch.	Head of Water in feet.	Time of observation in seconds.	Water delivered during observation, pounds.	Water delivered during one minute, in pounds.	Water delivered per minute in gallons.	Water delivered per minute in cubic feet.	Delivery as per Formula.	Radical of the Formula $\sqrt{\frac{D^5 H}{L}}$	Corrected Constant.
1	1	30	68	188	60	32	32	3.8	.512	.369	.0782	6.54
2	1	30	100	277	60	39	39	4.7	.624	.447	.0949	6.57
3	1	30	119	330	60	44	44	5.3	.708	.486	.1030	6.83
4	1	60	72	200	60	25	25	3 0	.400	.269	.0570	7.01
5	1	60	95	264	60	29	29	3.5	.464	.302	.0650	7.25
6	1	60	119	330	60	33	33	3.9	.528	.344	.0730	7.23
7	1	60	65	180	90	176	176	21.2	2.81	1.97	.419	6.70
8	1	32	90	259	75	214	214	25.8	3.43	2.34	.496	6.91
9	1	32	120	333	60	259	259	31.2	4 01	2.79	.570	7.00
10	1	32	70	194	60	135	135	16.2	2.16	1.45	.307	7.03
11	1	64	100	277	60	163	163	19.6	2.61	1.73	.367	7.11
12	1	64	120	331	60	180	180	21.7	2.88	1.90	.403	7.14
13	1	31	70	194	24	737	737	88.8	11.80	11.80	2.5	4.72
14	1	31	100	277	15	888	888	107.0	14.20	14.11	2.99	4.75
15	1	31	120	333	15	984	984	118.5	15.74	15.43	3.27	4.81
16	1	63.5	70	194	30	546	546	65.8	8.73	8.26	1.75	5.04
17	1	63.5	100	277	20	660	660	79.5	10.60	9.86	2.09	5.02
18	1	63.5	120	333	15	748	748	90.0	11.97	10.81	2.29	5.22
19	1	97	70	194	45	407	407	49.0	6.51	6.65	1.41	4.61
20	1	97	100	277	30	500	500	60.2	8.01	7.97	1.69	4.74
21	1	97	120	333	30	556	556	60.7	8.89	8.73	1.85	4.79

I have also obtained from G. W. Pearsons. M. Am. Soc. C. E., the blue print of a diagram which appears in the Transactions of this Society for February, 1876, and which diagram, with some modifications, was subsequently published in the *Engineering News* for December 24th, 1887. In a letter accompanying said diagram, Mr. Pearsons makes the following statement:

"I have noted on the blue print you ask for, your quantities, and would add the following for your consideration. We found that our other plunger pumps here required packing almost when new; that a very thin film of water around an unpacked plunger made a serious loss, and my experience with Worthington pumps leads me to think that you will find, on trial (pump under pressure against closed valves), that your loss is more than 5 per cent.; add to this uncertainty the 2 per cent. allowed in my diagram, and you may find that they do not vary seriously; another thing in this connection, I think, is that your pipes are smoother and evener than those we usually get here; my aim has been to reach as far as I could in quantities and be safe, but to be safe, as I have never known a case where a less friction than estimated would be injurious. As to the Quindardo mains, so far as I was able to observe last year, the flow corresponded very closely with the diagram. I hold that very little leakage occurs in the pipe itself; but in making such a test as you did, indicating a 70 000 gallon loss by leakage, I should want to be very sure about the stop valves. I have seldom found a valve tight after much use; have seen thirteen gates from 4 to 6 inches closed, and a large steam fire-engine have all it could do to keep the leakage clear, and have seen dozens of similar instances more or less closely approximating to this."

From the interesting report of Dexter Brackett, Assistant Engineer of the Boston Water Works, dated May 1st, 1882 (see City Document 124), I quote the following in relation to the Charlestown Works, built in 1864–65:

"The main pipes of this district are made of wrought-iron, coated inside and out with cement mortar. Fifteen years' use proved them defective, and they have been partially replaced by cast-iron pipes. It was expected that many leaks would be found from the cement-coated pipes, but these expectations were not realized. In a few cases the closing of a main gate, after all the services had been closed, showed a waste of from one to three hundred gallons per hour from the main or from the services between the main and the sidewalk shut-offs, but no leaks were discovered of sufficient magnitude to warrant the expense of uncovering a long line of main pipe."

From his report we also learn that in five different districts in which the population varied from 2 000 to 3 000 people, and where the ordinary

night draft had been running at the rate of from 50 to 60 gallons per head per day, Mr. Brackett was enabled, by carefully restricting waste, to reduce this night draft to the rate of from 9 to 15 gallons per head per day.

Replying to the inquiry of Mr. Fteley, I would say that the table of the results in pumping water through our 20-inch main, which appears above in this paper, was obtained from a consideration of six hundred and seventy-three observations. There are eight vertical columns in that table showing these results.

The following is a statement of the number of observations taken in each case, and the maximum and minimum results.

Column.	Given discharge per day in gallons.	No. of observations.	Range of observations from discharge as given. Below.	Above.
1	2 848 000	75	6 per cent.	3 per cent.
2	3 165 200	135	5 "	2 "
3	3 354 250	125	4 "	2 "
4	3 566 800	125	4 "	2 "
5	3 804 400	110	2 "	2 "
6	3 904 200	75	2 "	4 "
7	4 116 750	25	6 "	1 "
8	4 255 200	3	1 "	1 "

Mr. Fanning, in his comprehensive discussion, has furnished a diagram of co-efficients of flow in pipes under pressure for different size pipes and different velocities. It will be interesting to compare his theoretical results with those actually obtained by the Hackensack Water Company.

The following table shows this comparison, and also shows the results obtained from Mr. Pearson's diagram of flow of water in long pipes above referred to, as well as results obtained from the experience of Mr. Fteley:

Column.	Velocity in feet per second.	Friction Head per ~~100~~ 1000 Feet. H. W. Co. R.	Fanning.	Pearson.	Fteley.
1	2.00	0.729	0.791	0.928	0.773
2	2.24	0.876	0.983	1.136	0.970
3	2.36	1.029	1.085	1.288	1.076
4	2.52	1.316	1.232	1.401	1.226
5	2.68	1.337	1.388	1.557	1.387
6	2.76	1.490	1.464	1.651	1.470
7	2.92	1.645	1.629	1.852	1.647
8	3.00	1.797	1.713	2.017	1.738

Mr. L. L. TRIBUS, Jun. Am. Soc. C. E., submits the following memoranda. He desires his suggestions to be considered as simply an amplification of one point of my paper.

His point is well taken and would have been dwelt upon by me had I supposed the facts I have presented would have been received with such general interest.

I originally had no idea of doing more than to state approximately the results obtained from day to day during routine work. I have especially avoided any theoretical deductions from the facts presented in this paper.

Mr. Tribus says: "Owing to the large amount of matter given in Mr. Brush's paper, the point to which I refer could not be presented therein without confusion. It has not been since considered. My discussion is essentially theoretical though the data is as nearly as possible actual. The results obtained seem to come into slightly closer harmony with the conclusions reached by several well-known experimenters in hydraulics.

I refer to the statement that on the 20-inch pumping main, 75 000 feet in length, at about 15 000 feet from the engine, there is removed approximately 100 000 United States gallons daily, and at about 70 000 feet from same, another 100 000 United States gallons.

I therefore found on this assumption that in the respective portions, under the various given effective heads, the three quantities of water must move at different velocities, and therefore, the diameter and length being constant, the friction would vary with the squares of the velocities found.

By a simple algebraic formula, involving the given total effective heads and the squares of the velocities for known, and the required rate of friction due to each velocity for unknown quantities, I tabulated the following results, given in table on opposite page.

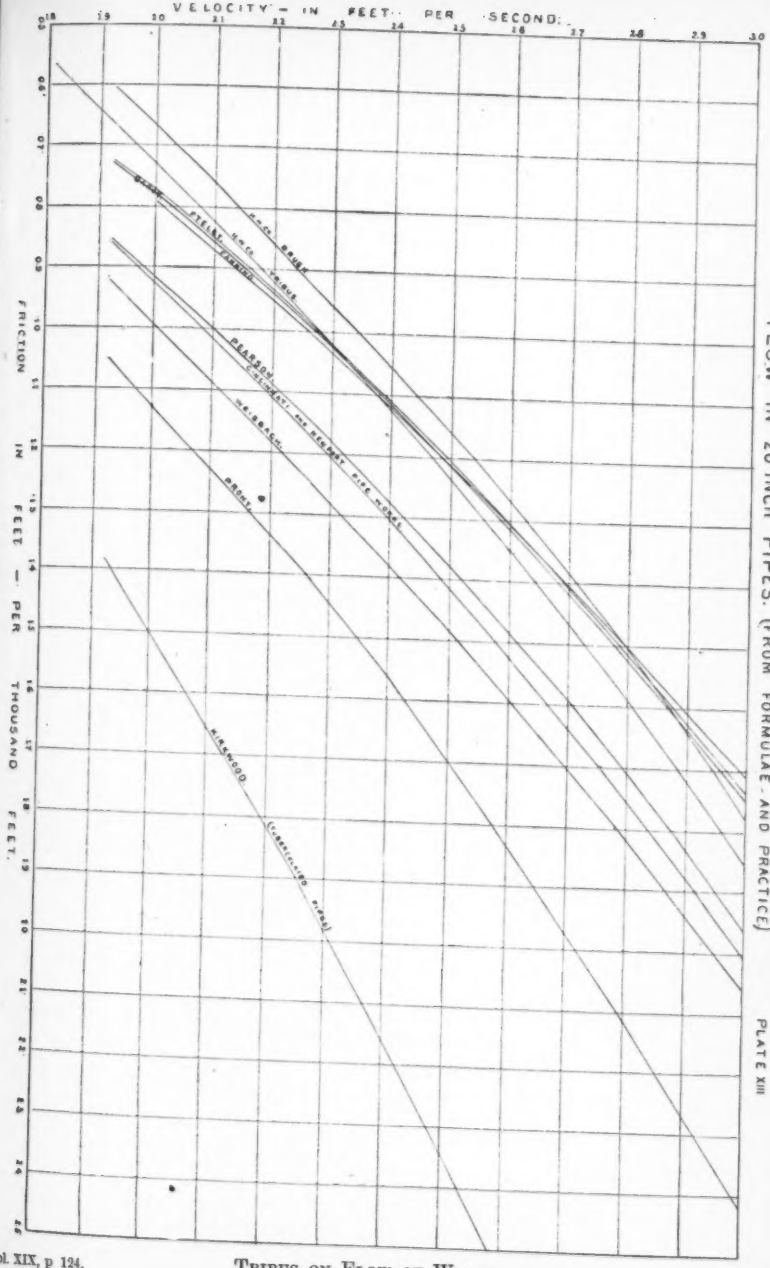
An inspection will show the great variation in several cases.

Plotting the results, with friction in feet per thousand as abscissas and velocity in feet per second, as ordinates, I assumed a curve that appeared to be a fair mean of the conditions found.

Plotting also, the results obtained in Mr. Brush's paper, I assumed another curve that seemed to express them fairly.

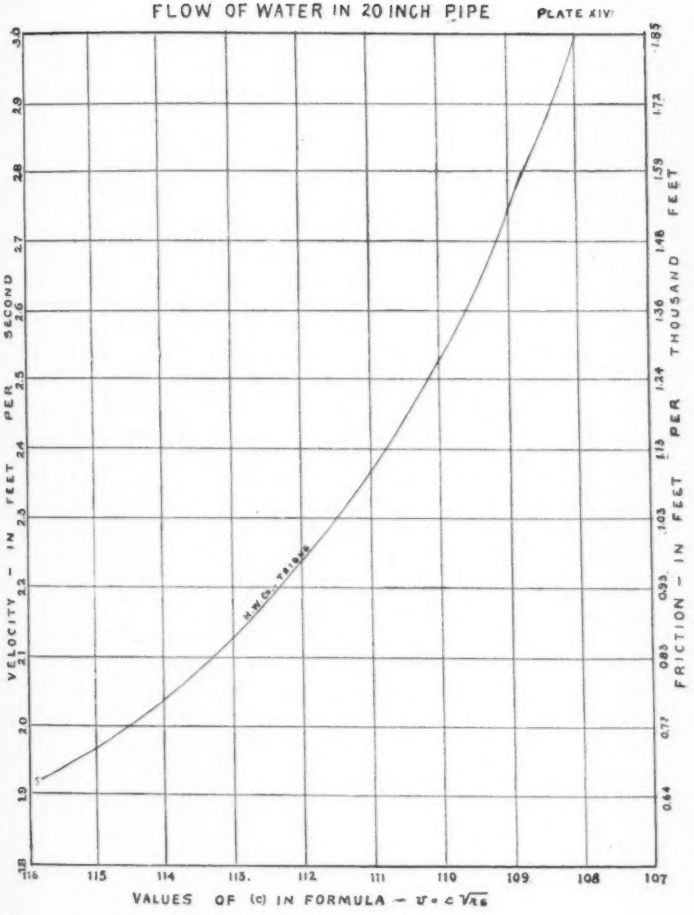
Plate No. XIII will illustrate this without further comment, and also the theoretical and experimental figures of other authorities as quoted in Mr. Brush's paper.

Plate No. XIV represents the curve that I assumed with corresponding values for c in the formula $v = c\sqrt{RI}$ varying from 115.8 for a velocity of 1.92 feet per second to 107.8 for 3 feet per second."



FLOW IN 20 INCH PIPES. (FROM FORMULAE AND PRACTICE)

PLATE XIII


FLOW OF WATER IN 20 INCH PIPE
PLATE XIV
VELOCITY — IN FEET PER SECOND
FRICTION — IN FEET PER THOUSAND FEET
VALUES OF (c) IN FORMULA — $v = c\sqrt{rs}$
H.W.C. 7.21.25
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.85
1.72
1.59
1.48
1.36
1.24
1.13
1.03
0.93
0.83
0.77
0.64
116
115
114
113
112
111
110
109
108
107

Effective Head in feet	43	55	66	77	89	100	112	123	135
Discharge United States Gallons in 24 hours	2 726 600	2 848 000	3 165 200	3 354 250	3 566 800	3 804 400	3 904 200	4 116 750	4 255 200
Velocity in feet per second	1.92	2.00	2.24	2.36	2.52	2.68	2.76	2.92	3.00
Friction in feet per 1 000	0.614	0.770	0.932	1.072	1.245	1.387	1.563	1.719	1.865

15 000 FEET FROM ENGINES. 100 000 UNITED STATES GALLONS REMOVED.

Discharge	2 626 600	2 748 000	3 065 200	3 254 250	3 466 800	3 704 400	3 804 200	4 016 750	4 155 200
Velocity	1.858	1.943	2.168	2.302	2.452	2.620	2.691	2.841	2.939
Friction	0.567	0.728	0.8714	1.02	1.177	1.3.5	1.483	1.626	1.79

70 000 FEET FROM ENGINES. 100 000 UNITED STATES GALLONS REMOVED.

Discharge	2 526 600	2 648 000	2 965 200	3 154 250	3 366 800	3 604 400	3 704 200	3 916 750	4 055 200
Velocity	1.828	1.873	2.097	2.231	2.381	2.549	2.620	2.770	2.868
Friction	0.548	0.674	0.814	0.958	1.11	1.255	1.405	1.546	1.706

In reply to a question raised during the discussion at the Annual Convention, I stated that the value of the tables on page 103 largely consisted in the fact that we were driven to the necessity of greater vigilance and more careful examinations to determine waste. The truth of this remark has been verified. Since that meeting careful and repeated night inspections have developed several leaks in our mains in the high service district, the aggregate loss from which leaks amounted to about 125 000 gallons per day.

During the discussion there seems to have been an inference drawn from my paper to the effect that I thought part of the leakage was through the pipe. I did not intend to convey that idea at all, but rather that in every extended distribution system there were more or less cases of defective joints due to carelessness in the original laying of the mains, or to water-hammer after the mains are laid, and that the waste from such joints or from cracked pipe frequently did not appear on the surface of the ground.

There is one point, presented in this paper, that has not been considered in the discussion, and that is the maximum amount of water that can be economically pumped through a given main and the relative cost at different velocities. It seems to me that the results of actual experience in this matter would be information of very great practical importance.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

396.

(Vol. XIX.—October, 1888.)

THE THEORY OF AQUA AMMONIA ENGINES, WITH RESULTS OF TESTS UPON AN ENGINE OF THIS TYPE OPERATING AN EDISON INCANDESCENT LIGHTING PLANT.

By EDWARD E. MAGOVERN, Jun. Am. Soc. C. E.

READ SEPTEMBER 5TH, 1888.

The writer, in the course of professional work, has recently been called upon to investigate a system of power development, in which the vapor of aqua ammonia has been substituted for steam with remarkable findings, both as to economic and potential efficiency, and desires to communicate these results, together with an examination as to how far our present knowledge of the science of thermodynamics will explain or attempt to contradict the facts experimentally obtained.

The fact that the steam engine, as a prime mover, realizes in useful effect but about one-tenth of the available energy stored in the coal as heat, is so well known, that its mere statement, even to a layman, is deemed almost unnecessary. To the professional Engineer, however, whose function may be defined as the creating of profit for capital, the realization that by reason of the intrinsic physical properties of the medium commonly employed to convert the heat of the coal into work,

nine-tenths of the available energy of the fuel is wasted, awakens in the mind the question: May there not be, among the many liquids, and among the many gases whose properties have been determined and whose law of changes fixed by the patient labors of our physicists and chemists, some medium, liquid or gaseous, or both, which can be employed to transmit the heat from the coal to the engine, there to be converted into useful energy, without this enormous loss?

The question, father to the action, leads to a consideration of the causes of loss; and the possible remedy, the employment of a liquid having a lower latent heat of vaporization, instantly suggests itself. These, fortunately or unfortunately, are many in number, the principal of which are given in the subjoined list:

	Latent heat of vaporization in British thermal units.
Anhydrous ammonia	895
Alcohol	364 to 372
Bisulphide of carbon	156 to 212
Carbonic acid	298
Sulphuric ether	163 to 174
Turpentine	137 to 184
Mercury	157
Chymogene	175

Doubtless, it would appear to a novice, with the exception of anhydrous ammonia, whose latent heat is less than ten per cent. lower than that of water, a promising list. To the experienced Engineer, however, the inflammability, explosive or poisonous qualities of the vapor, the difficulty of confinement, the comparatively light density of the evolved vapor requiring a comparatively larger volume to carry the equivalent available heat, thus necessitating the employment of larger cylinders and other detractive qualities, make the outlook less promising, and the anticipations of enormous theoretical saving, sink, overwhelmed by difficulties, which, correctly or incorrectly, are considered insurmountable. Nor does the attempt at discouragement of the inventor cease here. Theoretical deductions from the infant science of thermodynamics not yet fully understood, and not yet subjected to crucial test, are hurled in phalanx against any attempt to shake the wasteful tyrant, steam, on his throne.

In a recent article, relevant to the subject in hand,* that eminent authority, Professor R. H. Thurston, M. Am. Soc. C. E., from whom

*Steam and its Rivals, Forum, May, 1888.

in former years the writer had the pleasure and profit of receiving instruction, sums up as follows:

"Comparing alcohol, ether, bisulphide of carbon and chloroform, the most promising of the available fluids, with water, and its vapor, steam, it was found that, as the well-known laws of thermodynamics indicate, all were of precisely equal efficiency if worked in perfect engines, within the same range of temperature, with no waste occurring other than that which has already been described in the earlier part of this paper as unavoidable."

To these conclusions, and to that portion of the article itself which treats of the efficiency of heat engines, and as far as the analysis is carried, the writer cannot except. But to conclusions based primarily on a consideration of the performance of vapors in the cylinder only, and then applied to the complete cycle of operations incident to an engine, with the fluid supplied and evaporated in a separate vessel, the reception of heat, being, not as provided for by Rankine, wholly at one absolute temperature, T_1, and its rejection wholly at another absolute temperature, T_2, but in a more complex and less readily understood manner, to these conclusions the writer objects, such application being incompetent, irrelevant and immaterial.

The fact that the efficiency of all vapors, in the cylinder, received at an absolute temperature T_1, and rejected at a lower absolute temperature T_2, can be approximately* expressed as Rankine has done (cylinder efficiency only, let it be remembered) by $\frac{T_1-T_2}{T_1}$, is not denied.

The conclusions above quoted it is understood were arrived at by Messrs. Gantt and Maury,† after a thermodynamic study of the fluids spoken of; expressed in other words, the conclusions mean, that at the same pressure and temperature there is the same amount of heat in like volumes of different gases. This correct conclusion might have been arrived at by a mere study of the physical properties of the gases without reference to thermodynamics, for Delarive and Marcet (Annales de Physique et de Chimie, tome 35, p. 5, tome 41, p. 78, tome 75, p. 113) and Heyward (Edinburgh Phil. Journal, Vol. X., p. 351) have shown

* My friend, and former instructor, De Volson Wood, Professor of Mechanical Engineering at Stevens Institute, was, I believe, the first to demonstrate that this formula is only approximately true.

† Van Nostrand's Magazine, 1884.

"that in saturated gaseous media the volume is directly as the latent heat;" again, Avogardo's law states: "in like volumes of all gases there is the same number of molecules," and as the product of the molecular weight and specific heat of all gases give constant result (proved by Du Long and Pettit, and accepted by such authority as Clerk Maxwell in his "Theory of Heat") it follows, as stated by Clerk Maxwell and by Cooke, in his "Chemical Physics," that there is the same amount of heat in like volumes of different gases.

One vapor, therefore, having had the necessary heat imparted to it and entering the cylinder, will, practical considerations aside, be as good for power purposes as any other vapor; and hence, Rankine's formula $\frac{T_1 - T_2}{T_1}$, containing no variable of gaseous composition, the only variables being the limits of temperature, is undoubtedly, for cylinder, or as it may be termed, gaseous, efficiency correct. Rankine, too, appreciated the above, and* states that "to fulfill strictly the above conditions of maximum efficiency between given limits of temperature, the elevation of the temperature of the fluid must be wholly performed by compression and the depression of its temperature wholly by expansion, operations which are in many cases impracticable, from the great bulk of cylinders which their performance would require." The most radical of the adherents of steam will hardly believe that a formula applicable, as Rankine has shown, to the elementary heat engine, should be applied to the class of engines mentioned by Professor Thurston. The formula, as above given, may be taken to represent only the expenditure of heat; its reception in most engines being apart from its point of expenditure, must therefore be separately considered, and if it can be shown that the reception of heat is, like its expenditure, independent of the fluid employed, the question of employing any vapor to replace steam as a medium for transmitting the heat of the coal to the engine, to be converted into power, is settled forever in favor of steam by reason of the absence of detractive qualities spoken of above.

A moment's thought will be sufficient to convince one, familiar with the physical properties of liquids and gases, that the reception of heat does involve a consideration of the nature of the fluid, otherwise the specific heat of all substances would be unity.

Again, practical considerations of the furnace and boiler efficiency

* Steam Engine and Prime Movers (1876 Ed.), p. 344, art. 268.

enter into a correct consideration of the resultant efficiency of the system, and it will readily be granted that the bare formula $\frac{T_1 - T_2}{T_1}$ involves no such considerations. To further exemplify this point, let two sister engines, each designed of maximum efficiency, be taken, and let it be granted that such a design is possible. Into one boiler we place liquid anhydrous ammonia, into the other water. Exposed to the ordinary temperature of the air in this latitude sufficient heat will be furnished by the atmosphere to generate gas within the ammonia boiler, and let it be supposed that the pressure so induced has, by regulating the volume of liquid ammonia introduced, become equal to one atmosphere; the water boiler, however, at any temperature below 212 degrees, will not give off sufficient vapor to create any pressure, and thus both boilers are at atmospheric pressure. Let the condensers of both these engines be located in the polar zone at a time when the temperature there is as low as — 37 degrees Fahr., and assume the condensers to be connected to the engines by an amply large pipe. Open the throttle valve of each engine, start the fly wheel, and if our reception of heat is the same in both cases, the result should be the same. But it is not; the ammonia gas discharged and entering the condenser is reduced to — 37 degrees in temperature and liquefies, relieves the exhaust side of the piston by condensation, and the motion will continue as long as the temperature of the condenser is maintained below — 37 degrees, and sufficient fluid injected into the boiler to permit the generation of an adequate supply of gas to fulfill the above conditions. The other engine has made a turn or two, and stopped; the temperature of the air is not sufficient to generate vapor for the operation of the engine. Have we attained perpetual motion without expenditure in the ammonia engine? Not at all; we have merely utilized the heat in the atmosphere, derived mainly from the sun, as Ericsson in his solar engine utilizes the sun's heat, though in another way.

Suppose we kindle a fire under the water boiler and in sufficient quantity to make its engine's motion and power equal to that of the ammonia engine (the exhaust vapor being condensed and frozen at the condenser), we then have

$$\frac{T_1 - T_2}{T_1} \text{ for steam} = \frac{T_1 - T_2}{T_1} \text{ for ammonia.}$$

Right; our engine or gas efficiency is the same. Is it obtained at

the same cost? No; by the amount of coal required to keep the steam engine going. The writer therefore concludes:

First.—That a thermo-dynamic analysis of the efficiency of fluid in any heat engine, save of the elementary type, should involve not only the efficiency in development of power at the engine, but also its efficiency in the reception of heat at the boiler.

Second.—That there is nothing in the science of thermo-dynamics, as understood to-day, which precludes the possibility of obtaining a less wasteful medium than water for the conversion of heat into mechanical energy.

The particular fluid which has of late years attracted the attention of scientific men as a substitute for water is aqua ammonia. This fluid, which is a mechanical solution of ammonia gas in water, possesses the following remarkable physical, chemical and mechanical properties:

1st. That while extremes of cold or pressure, or both, are necessary to liquefy ammonia gas, forming anhydrous ammonia, ammonia gas is readily absorbed by water and held, as one has seen very fine particles of solid matter held in water, mechanically. Therefore, the least application of heat causes the discharge of the gas, which has no latent heat of gasefication, not having become liquid. If an ordinary bottle of medicinal aqua ammonia be held at a temperature of 98 degrees for two or three hours, sufficient gas will be generated to force the cork from the bottle.

2d. The density of ammonia gas and steam are nearly equal, and therefore, at the same temperature, ammonia gas contains nearly the same amount of sensible heat, the only heat which can be utilized in the engine, per pound, as does steam.

3d. The vapor is non-explosive, and can be confined as readily as steam.

An analysis of the efficiency of the fluids, steam and ammonia, may be undertaken as follows:

Let T_1 and T_2 = the temperature of evaporation of aqua ammonia and steam respectively at the same gauge pressure.

= temperature of feed, for comparative work taken the same for the aqua ammonia as for steam.

W = weight of aqua ammonia required to produce $\left(=\frac{W_2}{q}\right)$

W_2 = weight of ammonia gas required per hour, about ten per cent. more than

W_1 = the weight of steam required per hour.

q = per cent. of ammonia present in W.

q_1 = " " " in feed liquid.

q_3 = " " " present in working vapor, reckoned $(W - W_2)$.

L_1 = latent heat of evaporation at gauge pressure for water.

L_2 = latent heat of evaporation at gauge pressure for the water of the aqua ammonia.

s_1 = specific heat of ammonia, taken as constant.

s_2 = " " steam " "

For Steam.

$(T_2 - t)\ W_1 = B.\ T.\ U.$, required with steam to raise W_1 pounds of water from temperature of feed to that of evaporation, and

$(T_2 - t)\ W_1 + W_1 L_1 =$ total heat of evaporation of W_1 pounds of steam per hour.

For Ammonia.

$(T_1 - t)(W_1 - W_2) + W_2 s_1 = B.\ T.\ U.$, required at start with aqua ammonia to raise the liquid to the temperature corresponding to its gauge pressure.

$q_3 (W - W_3) L_2 = B.\ T.\ U.$, required per hour to evaporate the water at a temperature corresponding to gauge pressure,

then for a run of n hours we have for total heat expended

(1) $[(T_1 - t)(W_1 - W_2) + W_2 s_1] + [q_3 (W - W_3)] L_2 n + n W_2 s_1$.

It will be observed that the first quantity is independent of the time of run, and therefore in a comparative test, the longer the time run the greater should be the economy shown; this theoretical deduction is confirmed by an inspection of the results of the tests.

Again, practical experience with the fluid has shown that its loss of heat is very small, so that the pressure on the boiler is little reduced after standing under banked fires during the night.

The quantity $q_3 (W - W_3)$ representing the amount of water from the aqua ammonia evaporated has considerable influence in reducing the

theoretical efficiency of the fluid; the cause of this will be explained further on. The value of the quantity, $q_3\ (W - W_3)$ may be arrived at as follows: A sufficient quantity of the gas leaving the boiler is drawn off by means of an aspirator, into a coil surrounded by water, and sufficient pressure by means of an air pump put upon the coil to ensure absorption of the gas, after the liquid has cooled; the latter is now drawn off by means of a cock into a suitable vessel, and its specific gravity determined by means of a Beaumé hydrometer.

The following table, published for the first time through courtesy of Mr. George Shepard Page, President of the Washington Ammonia and Chemical Company, gives the percentage of ammonia present in mechanical solution corresponding to different readings of the Beaumé hydrometer at 60 degrees Fahr.

Reading.	Specific gravity.	Per cent. NH_3
26 degrees	.89744	28.8
24 "	.90909	24.9
22 "	.92105	21.1
20 "	.93333	17.3
18 "	.94595	13.6
16 "	.95890	10.0

The above analysis does not include, as will be apparent later, the heat lost by the spray liquid from the boiler. If it is desired to carry the analysis to this point, the following formula will be found applicable.

To the above notation add the following:

t_2 = temperature of spray at exhaust.
t_3 = temperature of exhaust.
W_3 = weight of spray per hour containing
q_4 = per cent. of ammonia present in the spray.
t_4 = resultant temperature of the mixture of spray and exhaust.

$$t_4 = \frac{[(W_2 - q_3\ W_2)\, s_1 + q_3\ W_2\, s_2)]\, t_3 + [(W_3 - q_4\ W_3) + s_1\, q_4\ W_3)]\, t_2}{[(W_2 - q_3\ W_2)\, s_1 + q_3\ W_2\, s_2)] + [(W_3 - q_4\ W_3) + (s_1\, q_4\ W_3)]}$$

we have, therefore, W_3 pounds of spray liquid reduced from temperature T_1 to temperature t_4 by the spray, which loss hourly will be, in *B. T. U.*

$$[(W_3 - q_4\ W_3)\,(T_1 - t_4)] + q_4\ W_3\, s_1\,(T_1 - t_4),$$

the total expenditure of heat for n hours equation (1) must, therefore, be increased by this quantity, giving

$$(1a.)\ [(T_1 - t)\,(W_1 - W_2) + W_2\, s_1] + [q_3\,(W - W_3)]\, n + n\ W_2\, s_1 + n\left[[(W_3 - q_4\ W_3)\,(T_1 - t_4)] + q_4\ W_3\, s_1\,(T_1 - t_4)\right]$$

Following a line of argument, similar, doubtless to the above, many

engines employing aqua ammonia have been devised, and from time to time attracted much scientific attention; the one difficulty in the successful adaptation of the vapor seems to have been to affect the absorption of the vapor without back pressure on the engine.

Dr. F. A. P. Barnard, late President of Columbia College, commenting upon the ammonia engine of Froment at the Paris Exposition, calls attention to the economy possible in the employment of ammonia vapor over that of steam, and regrets that Froment's engine, opening, as it were, a field of such promise, should fail owing to the back pressure on the engine induced by the want of complete absorption of the exhaust vapor.

Experiments have been continued from time to time, new engines planned, and still this one defect proved to be unremedied; so impressed was the writer with the necessity of providing an adequate method of absorption, that when attention was first directed to the engine to be described below, the first question asked was: "How is the absorption effected, and what back pressure is found on the engine?" The answer to this will be found in the results obtained as given below. Suffice it to say, that the introduction of the spray vapor is made at such a point that the heat of absorption is removed by practically surface condensation, and that the final rising of the condensed vapor through a volume of supernatant liquid liquefies or absorbs whatever mechanically adherent vapor may be present.

Description of the Campbell Apparatus for the Utilization of the Vapor of Ammonia in Engines.*

The plant embraces one horizontal return tubular boiler, set in brick work, one single cylinder Porter-Allen automatic cut-off engine, the apparatus for absorbing the exhaust vapor, and the various appliances which serve for equipment. These are arranged in the general manner shown in the accompanying ground plan of the works. (Plate XV.)

Boiler.

The boiler, in general features, is of the horizontal return tubular type, but it differs from those in common use in being provided with superheating surface. The shell is completely filled with tubes arranged in horizontal rows. In the back connection, a division plate is introduced, laid horizontally, so as to cause the products of combustion to pass forward through the tubes in the lower half of the shell, which are immersed, and then backward through the superheating tubes in the

* The following description of plant is taken, in part, for reason of its clearness, from the report of George H. Barrus, Esq., M. Am. Soc. Mech. Engrs., who made a number of tests upon the plant, the results of which are hereinafter given.

upper half of the shell. On arriving at the back connection above the plate, they enter the base of the smoke stack. The front head of the boiler is protected from the direct contact of hot gases by means of a covering of asbestos board. The front ends of the superheating tubes are likewise protected for a distance of some 12 inches by cylindrical shields made of sheet-iron, which are placed loosely in the tubes. The boiler is fitted with a dome, the vapor from which passes into a vertical drum 30 inches in diameter, 8 feet high, which rests on the front end of the setting and drains back into the boiler. This drum adds to the vapor-space of the boiler, and secures a larger proportion of vapor-space to liquor-space than is usually provided in steam plants.

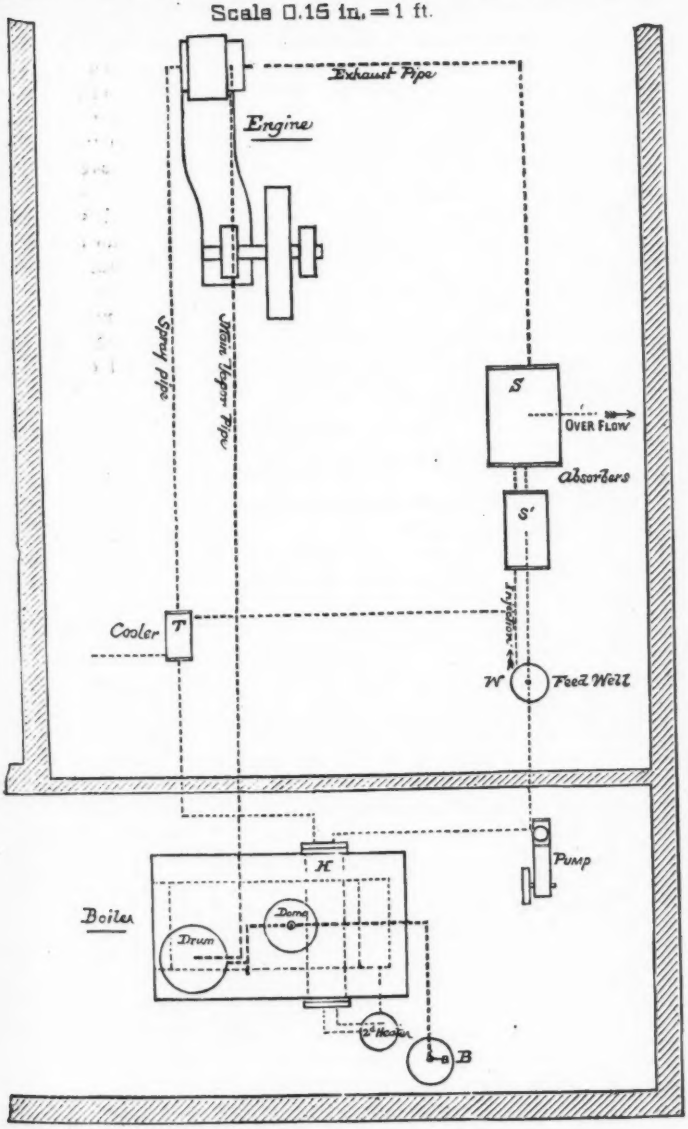
The connecting pipe is 4 inches inside diameter, and this is provided with a safety valve set at 110 pounds pressure, the vent of which is piped over into a tank (marked *B* on the plan), called the "dynamical reservoir," which is half full of aqua ammonia, the pipe descending to the bottom. A second safety valve set at 130 pounds pressure is provided, the vent of which passes to the atmosphere. The pipe which carries the vapor to the engine is attached to the top of the drum.

Owing to the insufficient natural draught of the smoke stack, the boiler is worked with artificial draught. For this purpose a small fan is provided (not shown on the plan), which is operated by power supplied by the engine. The discharge pipe of the fan connects with a brick passage leading from the back wall of the setting to the hollow bridge wall at the back end of the furnace, whence it passes into the ash pit through small openings at the bottom. The location of this passage, as also the general features of the setting of the boiler, are shown in the accompanying sketches. (Plates XV and XVI.)

The feed liquid is supplied to the boiler by means of a horizontal double acting fly-wheel pump, furnished with power from the engine. The cylinder is 3 inches in diameter, the stroke 9 inches, and the speed 70 revolutions per minute. The pump draws from the feed well and discharges through two heaters and a coil, the last-named being located in the back connection. The first heater (marked *H* on the plan), which is 11 inches in diameter and 7 feet long, is placed under the boiler behind the bridge wall, and buried in the setting. The feed liquor passes through a coil of ¾-inch pipe, 100 feet in length, which is wound in a spiral and placed within the cast-iron shell of the heater. The second heater, which is 12 inches in diameter and 4 feet high, is placed in a vertical position on the right-hand side of the boiler, outside the setting and near the back end. The feed liquor here passes through an additional length of 75 feet of ¾-inch pipe, put together with return bends. Surrounding the pipes in these heaters, is the "spray" as it is called, which is on its passage from the boiler to the liquefying apparatus of the exhaust vapor, and here the heat of the spray, which would otherwise be lost, is in part taken up. The feed liquor on leaving

Ground Plan showing general features of Plant.

Scale 0.15 in. = 1 ft.



the heaters passes through a coil containing 62 feet in length of 1-inch pipe, which is exposed to the products of combustion in the back connection below the division plate (not shown), and thence to the boiler.

Should the supply of liquor in the boiler become in any way reduced below the desired amount, it can be replenished from the "dynamical reservoir," and for this purpose a branch is carried to the reservoir from the suction pipe of the pump.

The vapor pipes are covered with hair felting laid outside of asbestos board, there being an air space between the board and the outside of the pipe. The dome of the boiler and the drum are covered with non-conducting cement, also laid outside of an air space.

The principal dimensions of the boiler, so far as they relate to the subject in hand, are given in Table No. 1. The figures for heating surface in the table do not include that of the coil in the back connection. The surface in this coil measures 21.4 square feet.

TABLE No. 1.

PRINCIPAL DIMENSIONS OF BOILER AND ENGINE.

BOILER—One Horizontal Return Tubular, set in brick work.

1	Diameter of shell	42 inches.
2	Length of shell	10 feet.
3	Number of 2-inch tubes below level of liquid	67.
4	Number of 2-inch tubes above level of liquid	68.
5	Inside diameter of tubes	1.75 inch.
6	Length of grate (net)	2.75 feet.
7	Width of grate	3.33 "
8	Width of metal and air spaces in grate	$\frac{3}{8}$-inch.
9	Area of water heating surface	369.3 square feet.
10	Area of steam heating surface	318.8 "
11	Area of grate surface	9.17 "
12	Collective area for draught through 67 tubes	1.12 "
13	Rated horse-power of boiler on basis of 15 square feet of water heating surface per horse-power	24.6 H. P.
14	Ratio of water heating surface to grate surface	40.3 to 1.
15	Ratio of steam heating surface to grate surface	33.6 to 1.
16	Ratio of grate surface to tube area	8.2 to 1.
17	Diameter of smoke stack	20 inches.
18	Height of smoke stack above grate	30 feet.

Engine.

The engine is of the Porter-Allen type. It is unjacketed, and is built in all essential respects in the manner customarily followed in engines of this kind. In these engines there are two steam valves and two exhaust valves. The steam valves consist of vertical slides, with faces on both the back and front sides. The back of the valve slides over the port. The front slides on a plate by which the valve is balanced, and this plate may be made to bear with greater or less force upon the valve by means of an adjusting bolt worked from the outside of the steam chest. It is needless to point out exactly how this adjustment is secured, further than to state that it is arranged so as to move the plate bodily toward the valve or away from it, as desired. These valves are operated by means of a link motion, the position of the block in which is varied by the action of the governor. The speed of the engine is controlled by this means and it is thus rendered an automatic cut-off engine. The exhaust valves are plain slides working in chests on the exhaust side of the cylinder. These chests and the spaces in the steam valves occupy so much volume that the clearance of the engine is made very large. The exact amount of clearance in this particular case has not been measured, but the assumed quantity of 10 per cent. corresponds to that of similar engines where it has been actually determined. The valve rods and piston rod of the engine are provided with metallic packing. One of the steam valve rods is kept cool by means of a stream of cold water. There is no oil cup attached to the cylinder and no lubricant is used in the cylinder other than that furnished by the ammonia. A small stream of liquid from the boiler is admitted while the engine is first starting, and at the time of stopping.

The principal dimensions of the engine, which relate to the subject in hand, are given in Table No. 2.

The load on the engine consists mainly of two Edison dynamo machines, class Y, having a nominal capacity of 225 amperes each. The speed of the dynamo shaft is 1 125 revolutions per minute when that of the engine is 205 revolutions per minute. The electrical plant is fitted with ampere meters, one for each dynamo, for showing the quantity of current delivered by the machines. The volt meter is not in use, but when the dynamos are working in normal condition, their electro-motive force is reported to be 93 volts.

The engine also drives the fan and feed pump which have been referred to, the pump which circulates the water in the absorbers, and a small amount of shafting.

TABLE No. 2.

ENGINE—Porter-Allen Automatic Cut-off, Single Cylinder.

19	Diameter of cylinder	11.5 inches.
20	Stroke of piston	20. "
21	Diameter of piston rod	1¾ "
22	Clearance (assumed)	10 per cent.
23	Horse-power constant 1 pound M. E. P., one revolution per minute	0.01037 horse-power.
24	Diameter of steam pipe	4 inches.

THE ABSORBING APPARATUS.

The absorbing process consists, first, in the introduction into the exhaust pipe of a jet of liquid from the boiler, called the "spray." The jet is ⅛ of an inch in diameter, and its point of entrance to the exhaust pipe is at the junction of the two branch pipes leaving the cylinder. The spray pipe is brought from the heaters, which have been referred to, and carried to a cooler (marked *T* on the plan), and thence to the exhaust pipe. The cooler consists of a coil of pipe enclosed in a vessel through which cold water circulates.* A branch from the outlet pipe of the cooler is carried to the feed well (*W*) for the use of the jet condenser, which has been referred to.

The exhaust vapor, after leaving the spray jet, passes to the first "absorber," (marked *S*), which is practically a surface condenser. This absorber has 500 tubes, ⅝-inch outside diameter, 41 inches long. The vapor then passes into the second absorber (*S'*), which is a surface condenser containing 150 tubes, ⅝-inch outside diameter, 40 inches long. Here the vapor is nearly all, if not wholly, converted to a liquid state, and the resulting liquid overflows into the well (*W*), from which it is returned to the boiler by means of the feed pump. The feed-well serves not only as a storage reservoir for the feed liquid, but also as a jet condenser, if necessary, for converting any vapor which remains into the liquid state.

The "cooler" and the "absorbers" are kept cool by means of a current of circulating water, part of which is supplied by the city hydrant, and part by a small centrifugal pump (not shown), which is fed with sea water drawn from North River, near where the works are located.

GENERAL CONDITION OF THE PLANT.

As far as can be judged by a somewhat careful examination, the plant appears externally to be in excellent working condition. An examina-

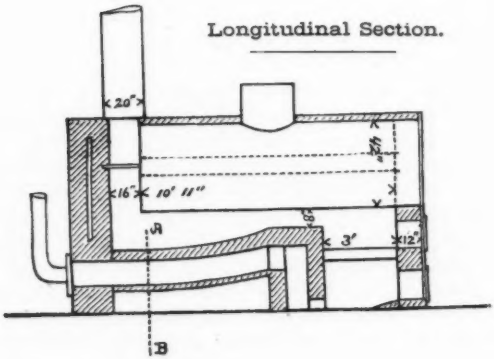
* This cooler has, subsequent to the tests, been found unnecessary, and has been dispensed with.

Sketches showing general features of

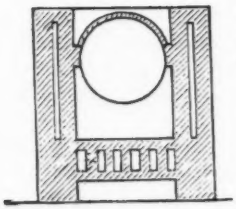
Boiler Setting.

Scale 0.15 in. = 1 ft.

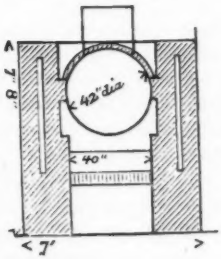
Longitudinal Section.



Section at A B.



Cross Section through furnace.



tion of the engine for leakage, however, revealed the fact that, in this particular, the plant is not in good condition. The valves and piston were tested for leakage when the engine was at rest, by applying the pressure of ammonia gas to them, and observing the amount of vapor which leaked through. The steam valves were tried by setting the rocker arm, which moves them, at mid-throw, in which position the ports are both covered, and opening the throttle-valve. The leakage was made to appear through the open indicator cocks. It was found that the valve at the crank end was nearly tight, but the valve at the head or front end leaked badly. Adjusting the balancing plate at this end produced no sensible improvement. The piston and exhaust valves were tested by placing the piston first at one end of the cylinder and then at the other end, and in each position opening the throttle-valve. In one position the piston and valve at one end were tested, and in the other position the piston and valve at the opposite end: The test consisted in admitting the full pressure of vapor, then shutting the throttle-valve and observing by means of repeated trials at the indicator cocks, the time when the vapor had all escaped from the cylinder. The vapor had all escaped from the front end of the cylinder at the expiration of two minutes from the time the throttle-valve was closed, and from the crank end at the expiration of only half a minute. This test does not show the exact location or amount of the leakage, but the writer draws the conclusion that the piston is fairly tight, and that both exhaust valves leak, the front-end valve a small amount, and the crank-end valve quite badly.

These remarks apply to the leakage at the time of the test of March 8th to 12th. Subsequently the crank-end steam valve became injured, and at the time of the tests of April 16th and 29th, although it had been repaired, it was still in an imperfect condition, as the leakage test revealed. Both steam valves on the last test leaked very badly. The exhaust valve and piston appeared to be in about the same condition as before.

The inside of the cylinder was examined by the writer, and found smooth, bright and free from corrosion. The steam valve at the front end was also examined, and both its faces, and the seats on the chest and balance plate, were likewise found in good condition.

The three leaks above mentioned operate against the economical working of the plant as follows:

First.—Steam leaks, (*a*) by raising the mean pressure during expansion above that required to accomplish its work and regulated by the engine through the cut-off. (*b*) Unnecessarily supporting the temperature during expansion, thereby not only wasting heat but also requiring more condensing water to cool the rejected fluid.

Second.—The exhaust leak, by raising exhaust temperature by means of unexpended heat in the fluid, which otherwise would, if imprisoned until release occurred in the regular way, yield its heat in accomplishing

work, but which, under the present conditions, demands an increased volume of condensing water for its reduction to the feeding temperature.

The present eccentric and link is not of the latest pattern of the Porter-Allen engine. The cards now exhibit the maximum possible point of release corresponding to the late compression. The more modern link, with the greater throw, permitting a later release with a later compression (thus approaching as nearly as is possible under the existing conditions of speed a card of the so-called Corliss type), would, in the writer's opinion, show an even more economical result, for the reason that the initial temperature of the fluid being considerably less than that of steam at a corresponding pressure, the initial condensation and subsequent re-evaporation would necessarily be less; and, therefore, from a thermodynamical point of view, the compression should be less than in an engine using steam as a working fluid, and consequently the work done in compressing could be reduced in a like ratio, thus increasing the efficiency of the machine.

The Results of the Experiments.

The experiments were conducted on a comparative basis, *i. e.*, the plant was operated with steam and with ammonia, the same observations being taken in each case; the results are given in the following table:

	1	2	3	4	5
Number of test					
Date of test	March 8th	March 9th	April 16th	April 29th	March 12th
Experimenter	Barrus	Barrus	Barrus	Magovern	Barrus
Vapor used	Ammonia	Ammonia	Ammonia	Ammonia	Steam
Fuel used	Anthracite	Anthracite	Anthracite	Anthracite	Anthracite
Duration of tests, hours	8	10	7.45	10	8.005
Weight of coal consumed, pounds	1 400	1 400	1 098	1 550	1 453
Weight of ashes, pounds	.....	139	90	68	138
Per cent. of ashes	.....	9.9	8.2	4.38	9.5
Coal consumed per hour, pounds	175	140	147.4	155	181.5
Coal consumed per square foot of grate per hour, pounds	19.09	15.27	16.07	16.90	19.98
Injection water per hour, pounds	.....	.....	372.8	500.1	.....
Average gauge pressure, pounds	100	95.5	86.6	89.45	66.5
Temperature at throttle	.....	304°	301°	324°	.....
Temperature of exhaust	.....	.....	180.8°	180.5°	.....
" spray	.....	280°	271°	279°	.....
" feed	.....	167.6°	167°	173°	.....
" uptake	.....	390°	394°	416°	394°
" Croton	.....	.....	49.5°	.....	.....
" sea water	.....	.....	42.7°	46.6°	.....
" discharge	.....	.....	104.2°	92.5°	.....
Vacuum, inches	.....	11.5	11	7	.....
Revolutions	205.2	204.5	201.5	200.14	198.3
Mean efficiency, pressure	29.05	27.13	26.99	28.49	15.7
Indicated horse-power	61.8	57.53	54.00	59.25	32.26
Coal consumed per horse-power per hour	2.832	2.433	2.729	2.616	5.626

Average..... 2.652

An inspection of the above tables will show:

First.—That with a boiler capable of supplying an engine with steam but for 32.26 horse-power, it was found capable of furnishing to the same engine, when ammonia was substituted for steam, sufficient vapor for developing 58.14 horse-power at a lower rate of combustion, thus furnishing an increased potential capacity of over 80 per cent.

Second.—That in an engine of modern type, requiring 5.626 pounds of coal per horse-power per hour when operated with steam, the consumption fell 2.974 pounds of coal per horse-power per hour, or over 53 per cent.

It may be urged by some that a portion of this economy may be due to the engine being practically a condensing engine when ammonia is used. The writer is not inclined to accept this view of accounting for the economy.

First.—Because the cards show but little vacuum in the cylinder, the value of which, when figured, will be found to be less than 10 per cent.

Second.—Because no vacuum pump is employed.

Third.—Because there has yet to be called to our attention an engine whose efficiency, by virtue of conversion from non-condensing to condensing, has been increased over 50 per cent. economically and 80 per cent. potentially.

The performance of the Porter-Allen engine in this case was not what might have been expected from so good an engine. The writer attributes it to two causes:

First.—To the load being lighter than that of maximum economy.

Second.—To the low boiler performance, being but 7.864 pounds of water per pound of coal under actual boiler conditions.

The engine, with a good boiler and run to its rated capacity, would be capable, in the writer's judgment, of developing a horse-power, with steam, for the expenditure of about 4½ pounds of coal per hour.

The poor boiler performance affected the results of both fluids equally; the low power of the steam trial affected the economical generation of power slightly more in the steam than in the ammonia test, though how much would be difficult to say.

The discrepancy between the theoretical and actual performances of aqua ammonia, as before intimated, must not be overlooked. The writer attributes the discrepancy to the phenomena that Faraday and others have observed, viz., that at all temperatures above freezing, water gives off vapor, though it is not completely vaporized until it attains a temperature of boiling dependent upon the pressure.

The writer believes that considerable water is vaporized with the liberation of the ammonia, and cites in evidence of this belief, the large amount of heat rejected in the circulating water shown by its quantity and rise in temperature.

INDICATOR CARDS, TAKEN WITH TABOR INDICATOR FROM A PORTER-ALLEN ENGINE, USING AMMONIA GAS IN THE CYLINDER.

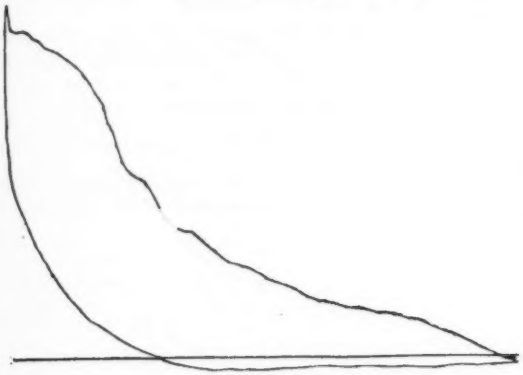
SCALE OF CARD 40.

TIME 1:45 P. M.

Average revolutions per minute 200.14.

Boiler Pressure 90 lbs.

Vacuum in Feed Well 7 in.



Back End.

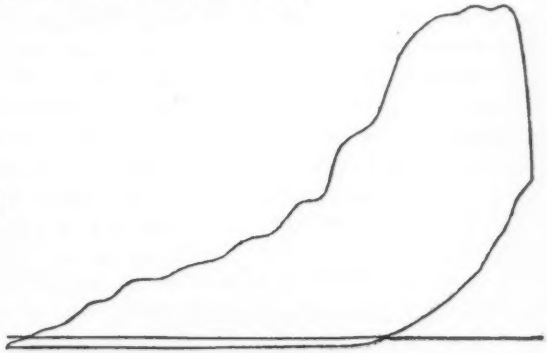
SCALE OF CARD 40.

TIME 1:45 P. M.

Average revolutions per minute 200.14.

Boiler Pressure 90 lbs.

Vacuum in Feed Well 7 in.



Crosshead End.

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PLATE XVII.

The steam vapor present, though undesirable from an economical point of view, is desirable in a practical way by reason of its assistance in the absorption process.

In conclusion, the writer desires to reiterate, and believes he has demonstrated in both a theoretical and practical way, the statement that a calculation of the efficiency of an engine, save of the elementary type, by the formula $\frac{T_1-T_2}{T_1}$ is incomplete, unless its method of heat reception is, like its expenditure, independent of the nature of the fluid employed; if the fluid is supplied as a permanent gas, such as air, hydrogen, etc., the Rankine formula can properly be applied; where, however, different liquids, with varying latent heats are employed, the $\frac{T_1-T_2}{T_1}$ formula is insufficient, as it involves no consideration of the varying latent heats which must be supplied by the expenditure of fuel, and are therefore part and parcel of a consideration of the efficiency of the system.